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(54) **TWO-AXIS SENSOR BODY FOR A LOAD TRANSDUCER**

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**G01L 5/16** (2006.01)  
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(58) **Field of Classification Search**

CPC ..... G01L 5/00; G01L 1/26; G01L 5/16; G01L 5/161; F16B 1/00

See application file for complete search history.

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*Primary Examiner* — Lisa Caputo

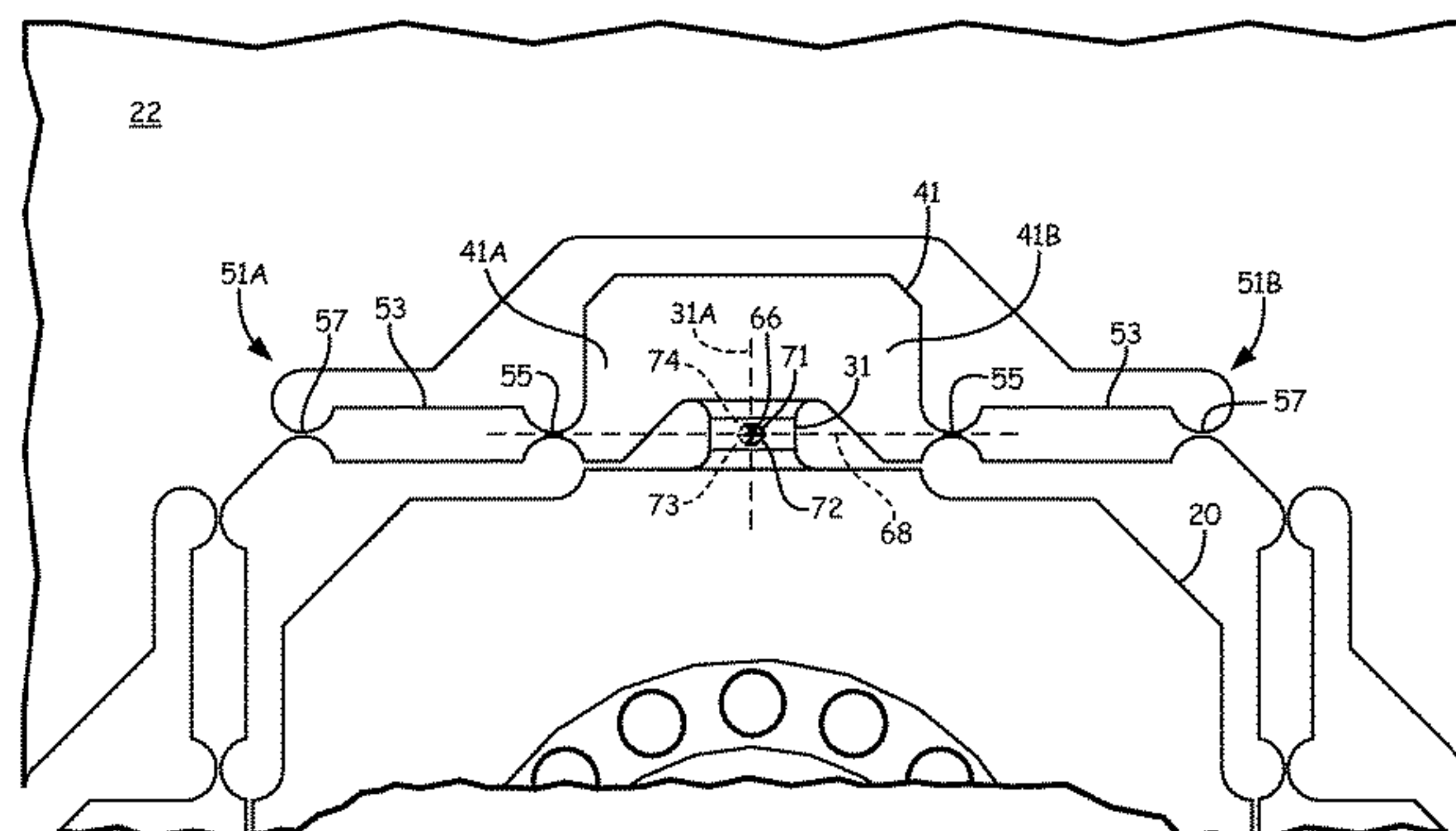
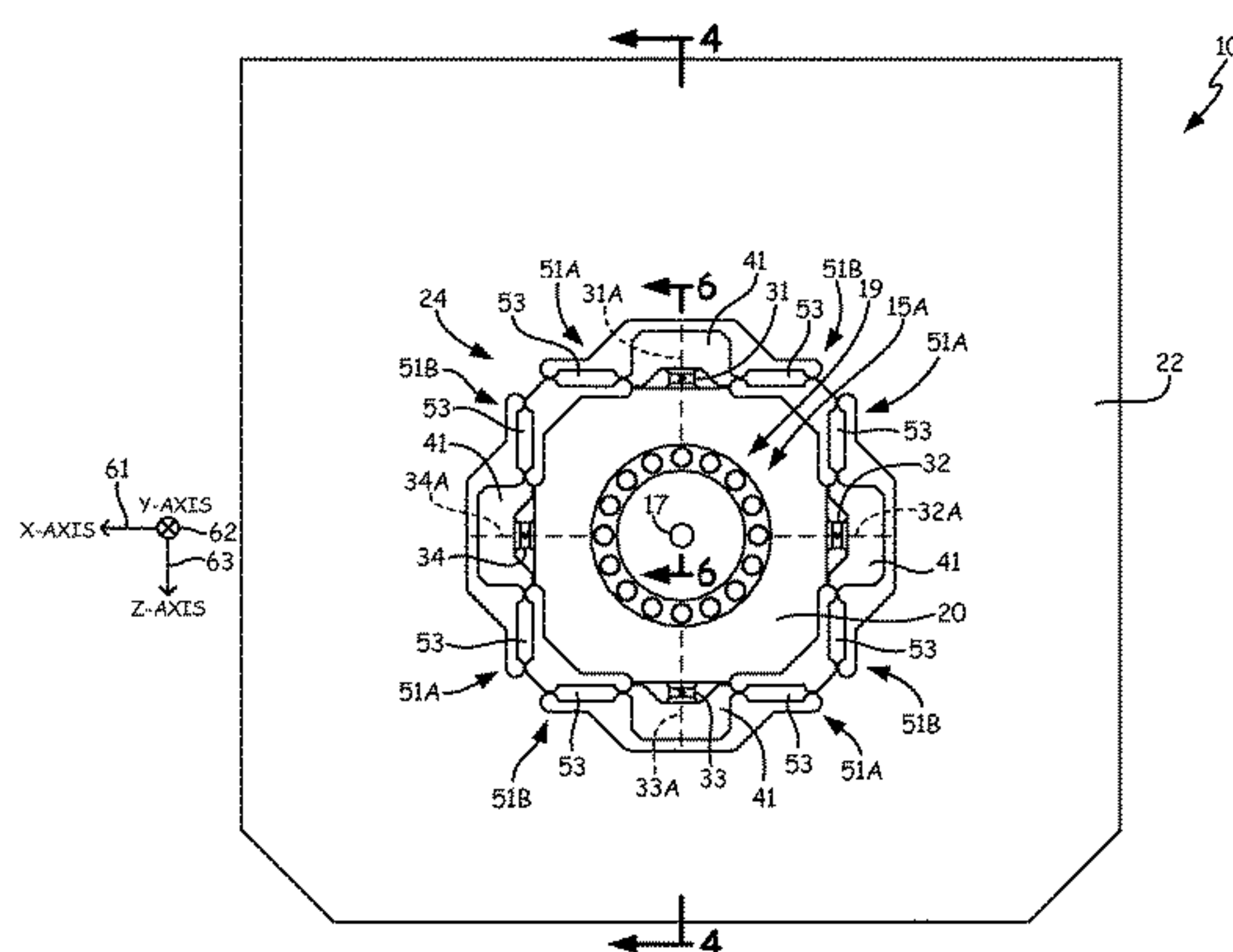
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(57) **ABSTRACT**

In one aspect, a transducer body includes a support having clevis halves. The sensor body includes a generally rigid peripheral member disposed about a spaced-apart central hub joined to each of the clevis halves. At least three flexure components couple the peripheral member to the hub. The flexure components are spaced-apart from each other at generally equal angle intervals about the hub; the sensor body further including a flexure assembly for some flexure components joining the flexure component to at least one of the hub and the peripheral member, the flexure assembly being compliant for forces in a radial direction from the hub to the peripheral member. Each flexure assembly is config-

(Continued)



ured such that forces transferred concentrate strain at a midpoint along the length of each corresponding flexure component.

**36 Claims, 30 Drawing Sheets**

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**G01M 9/02** (2006.01)  
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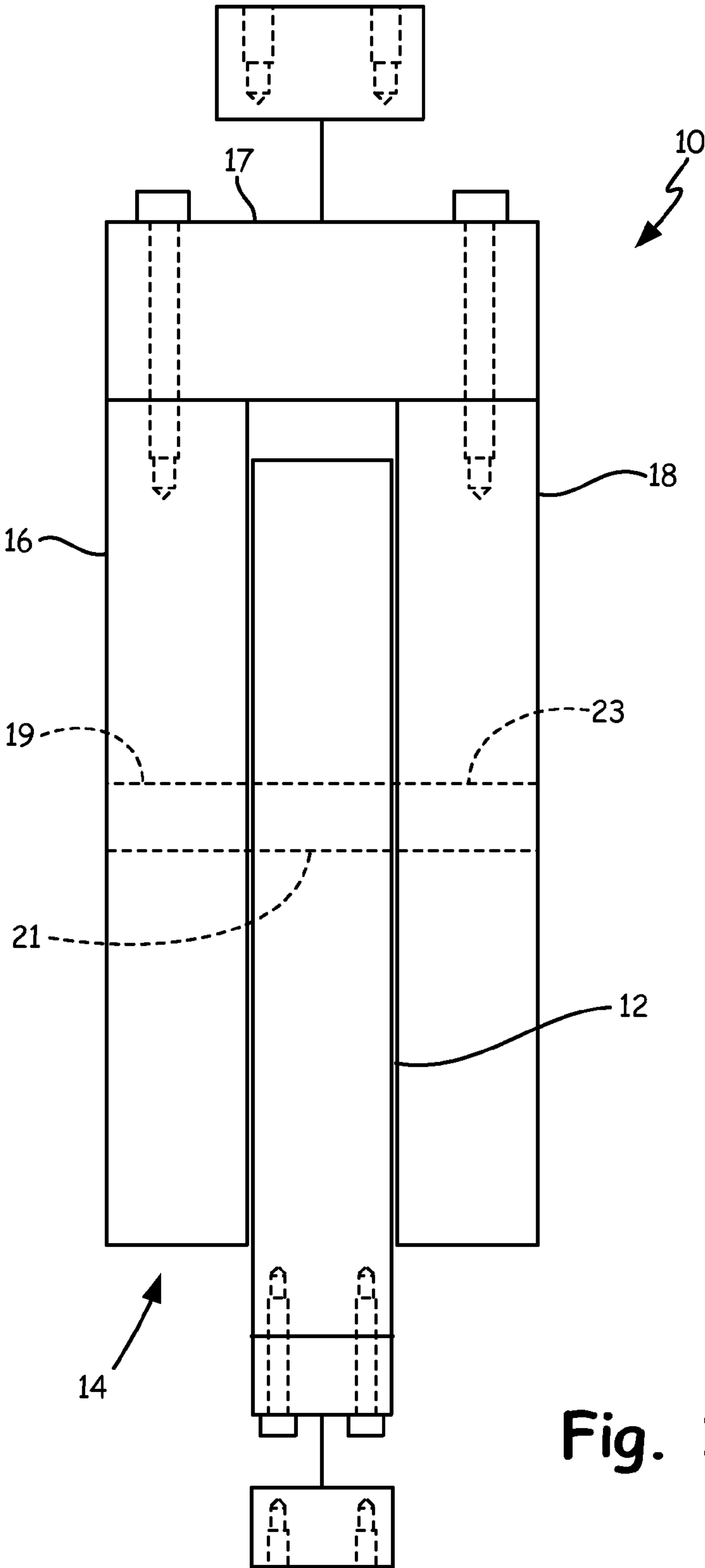


Fig. 1

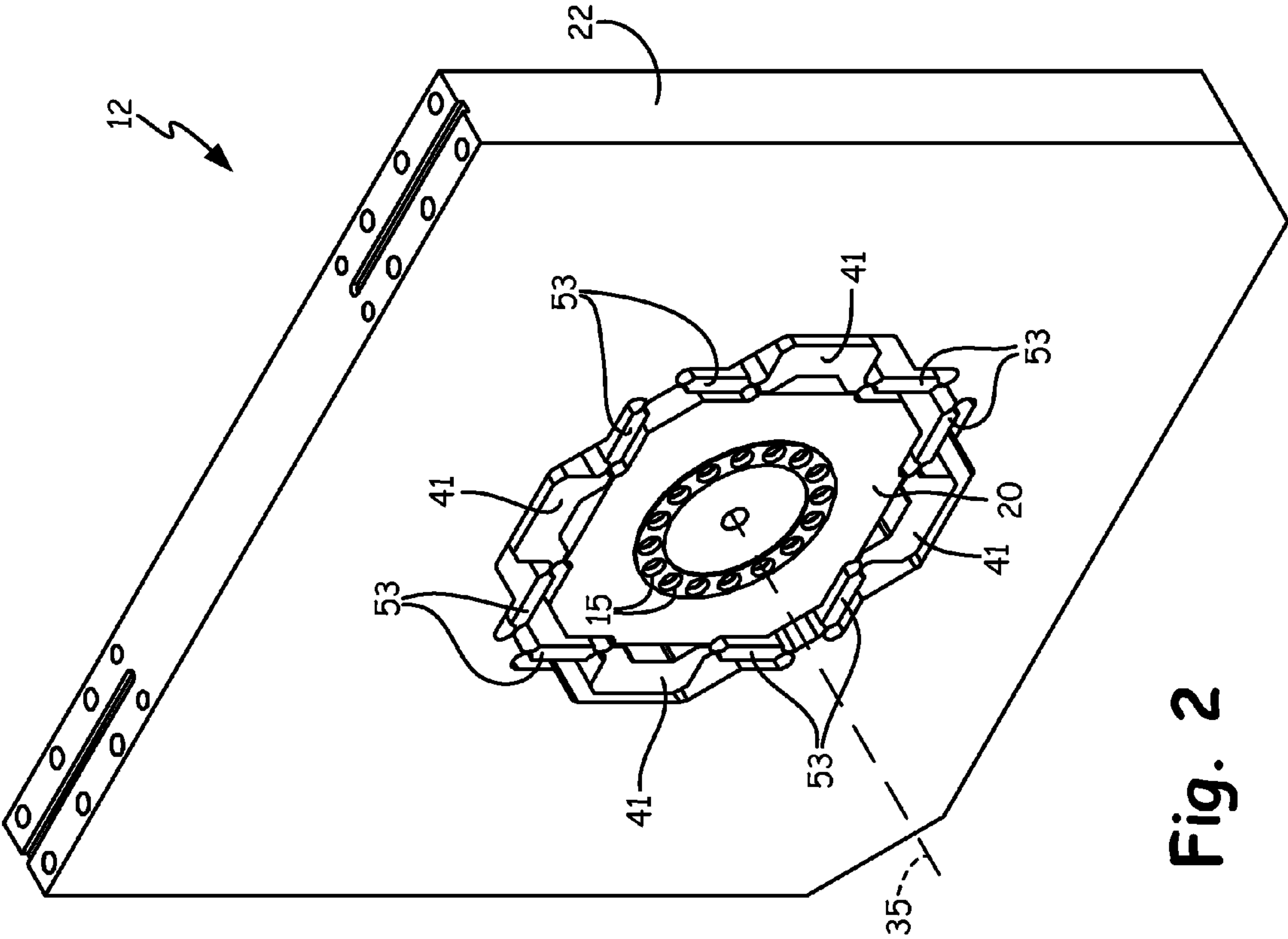


Fig. 2

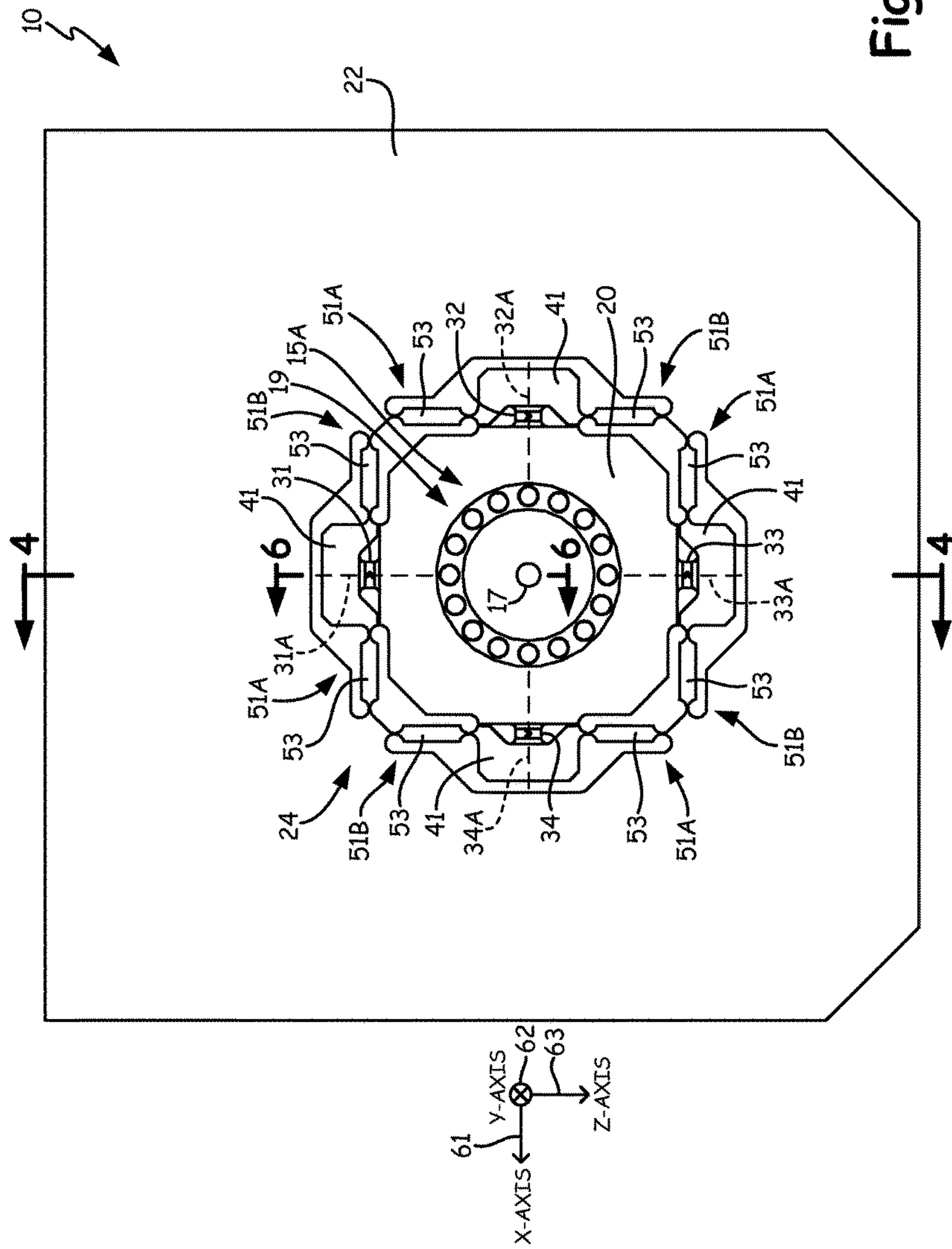


Fig. 3

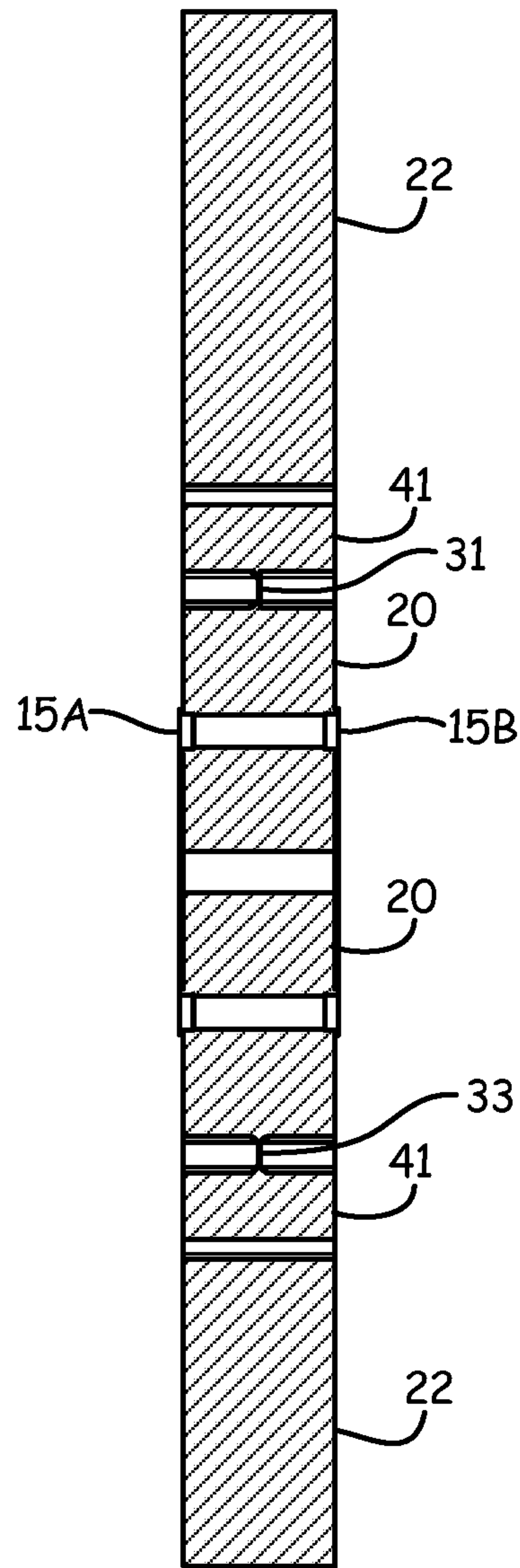


Fig. 4



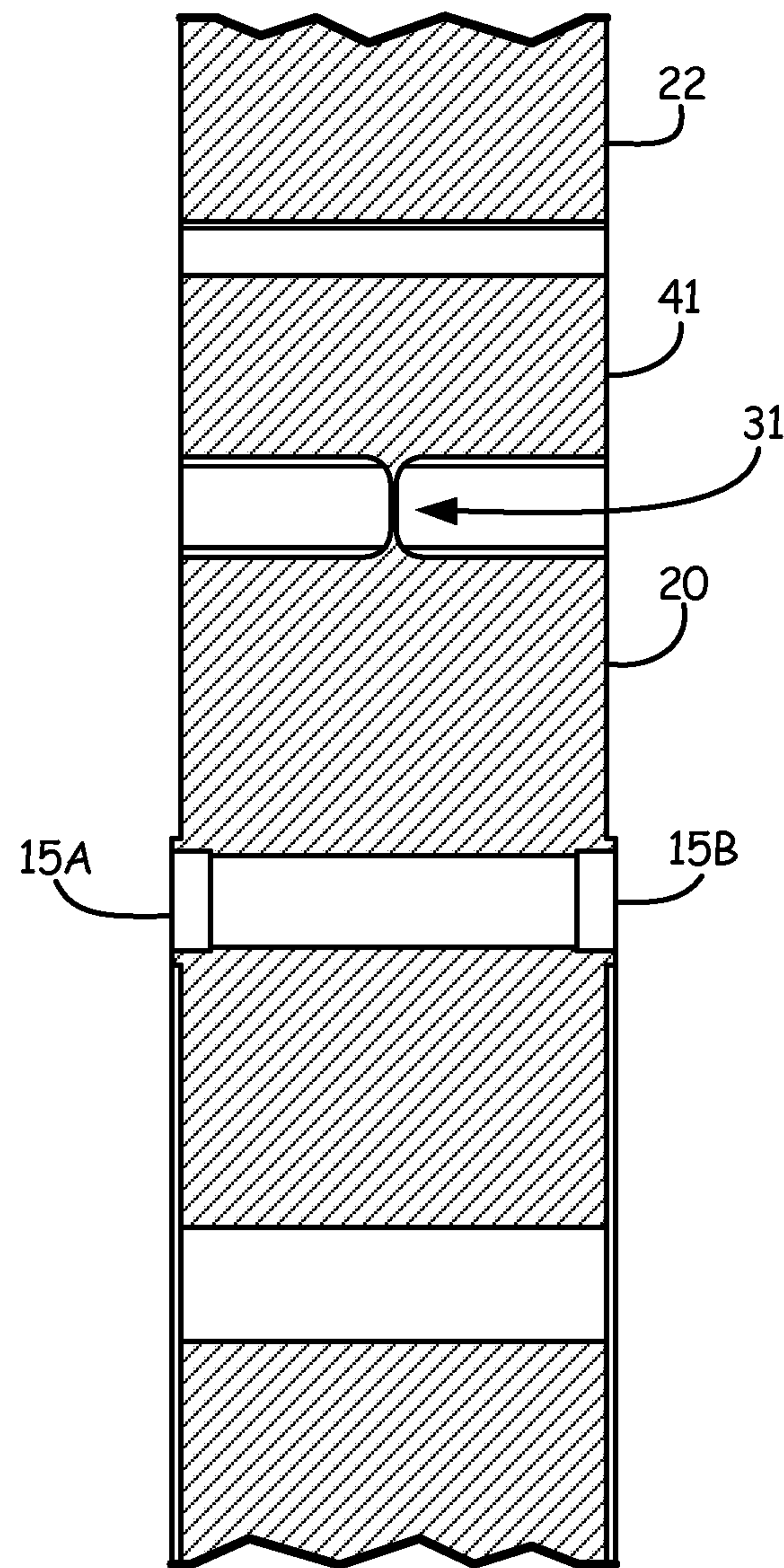


Fig. 6



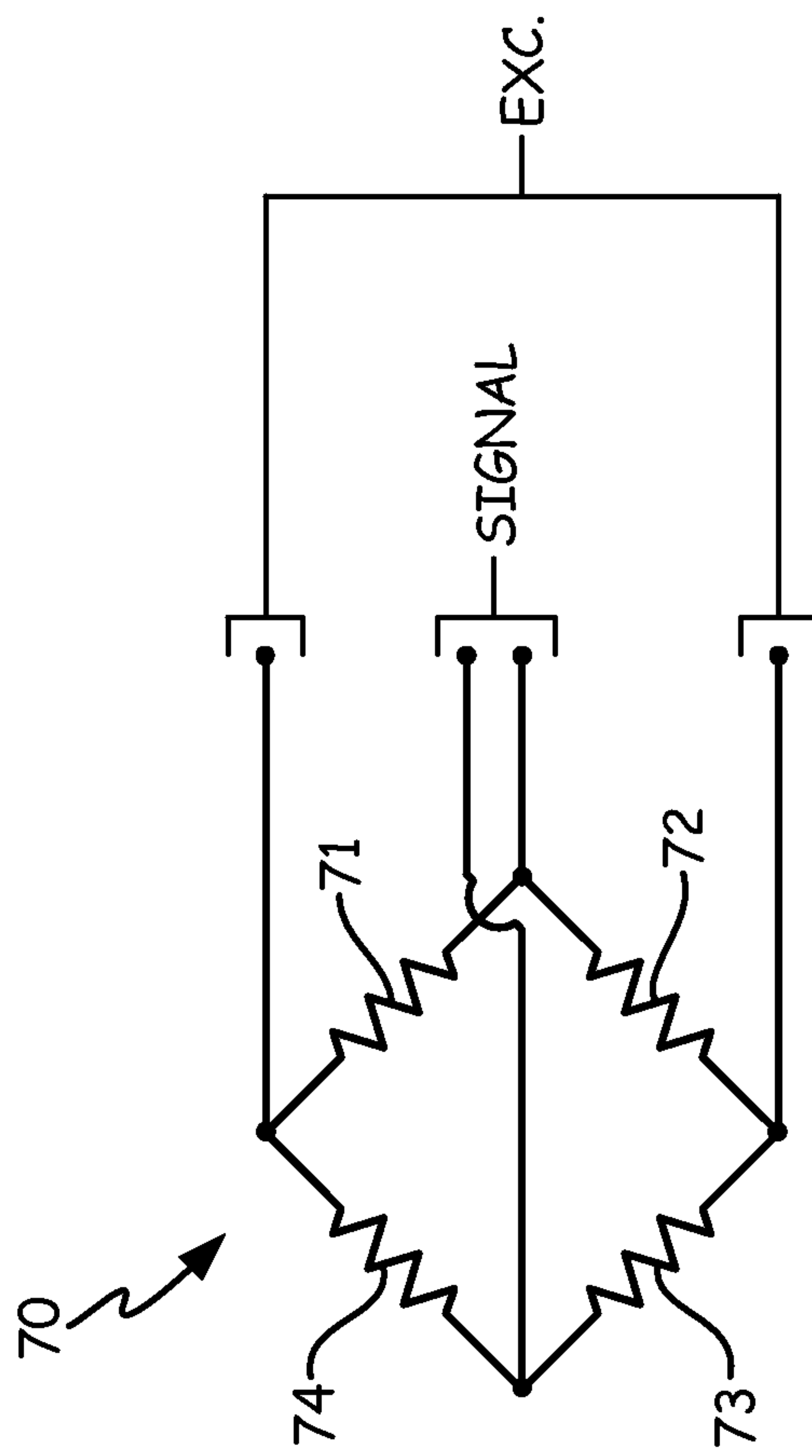


Fig. 7

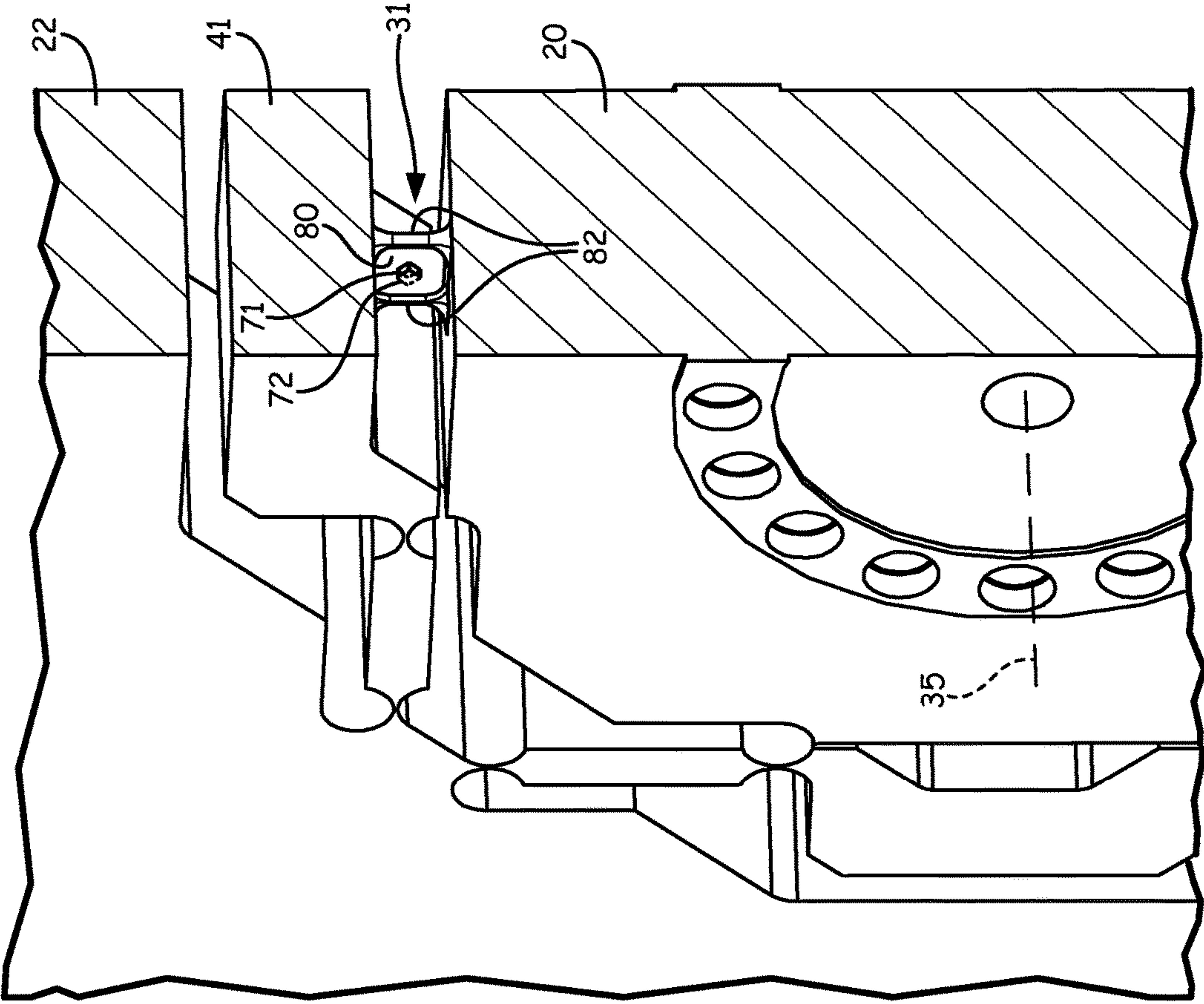


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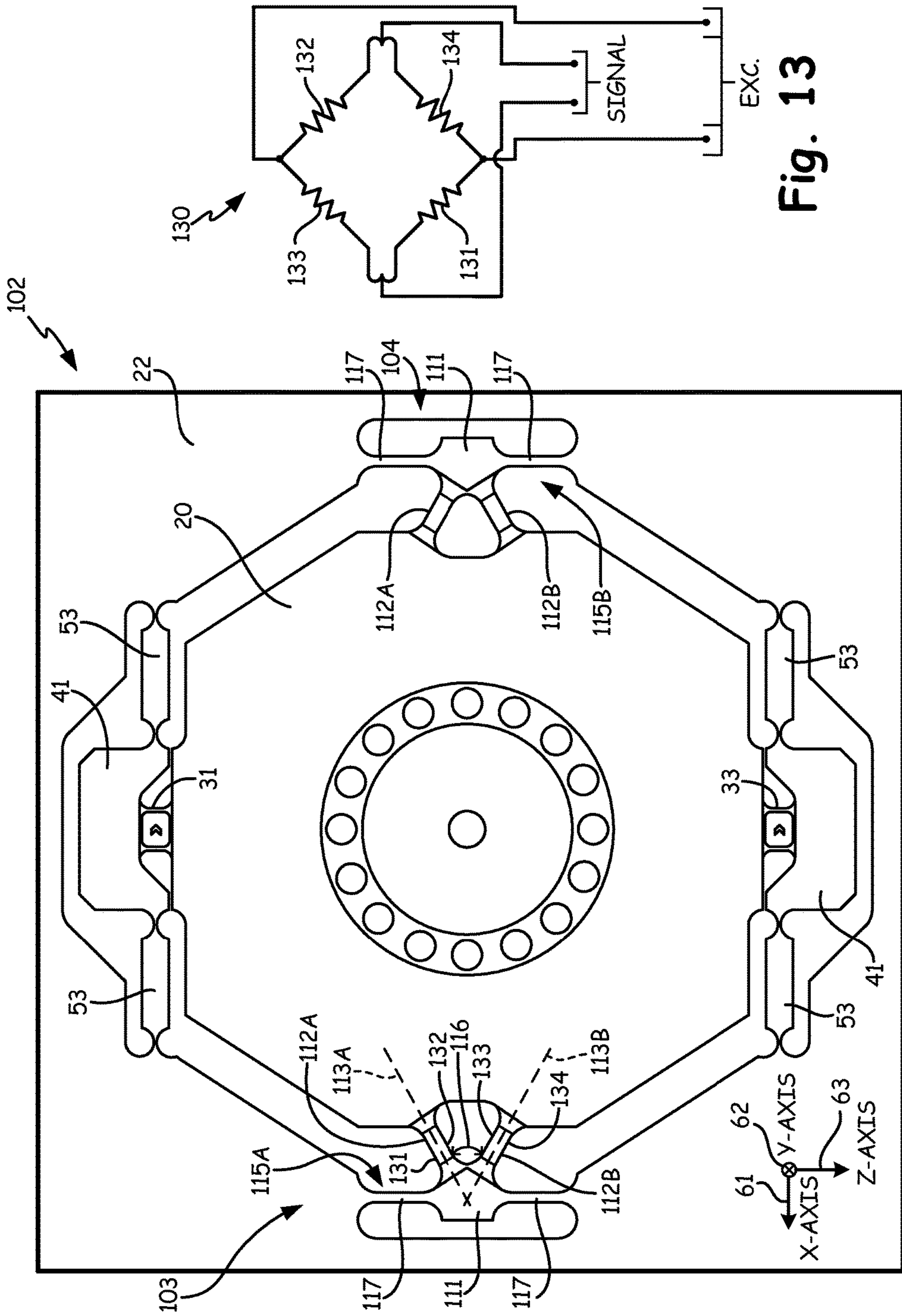


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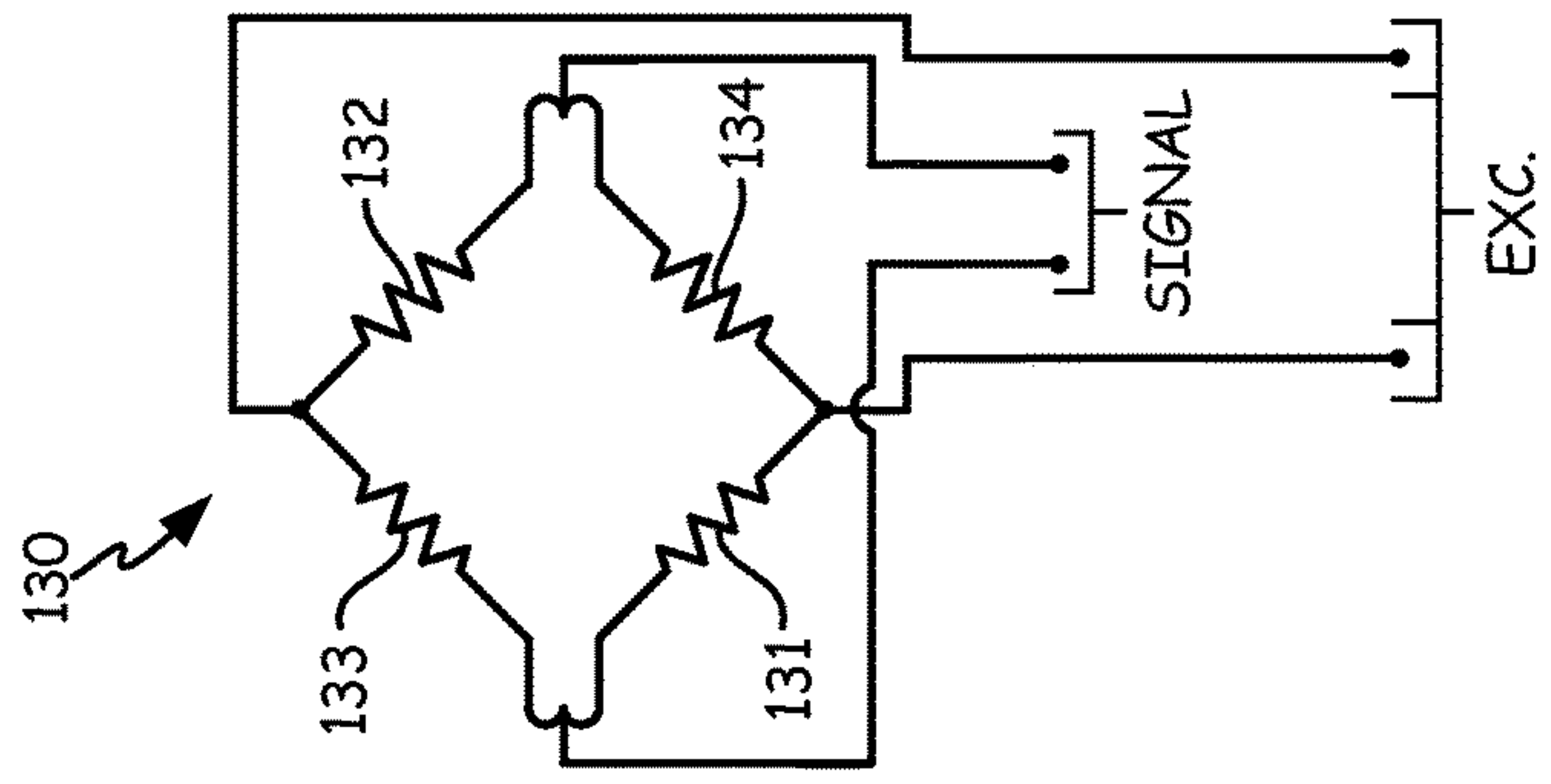


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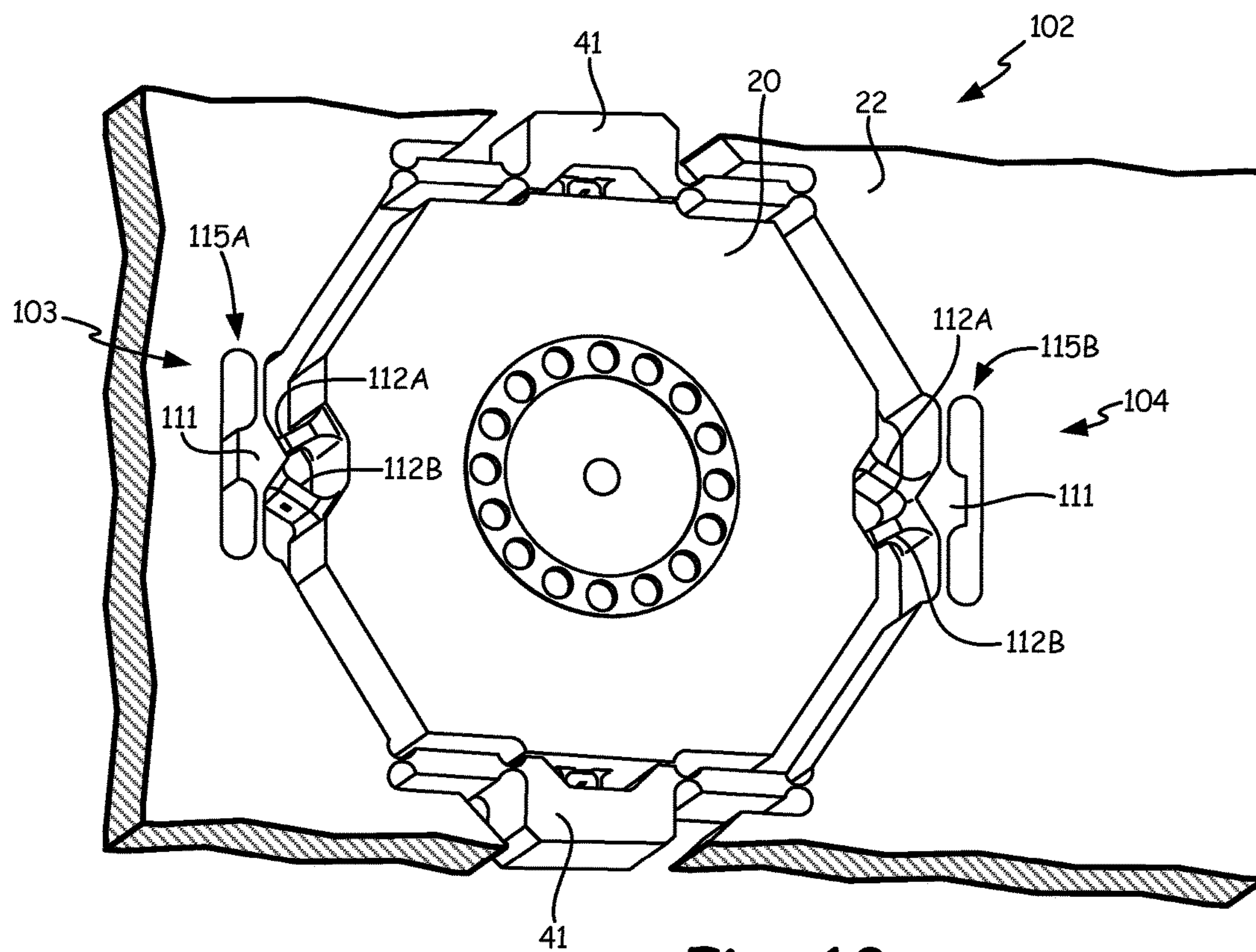


Fig. 10





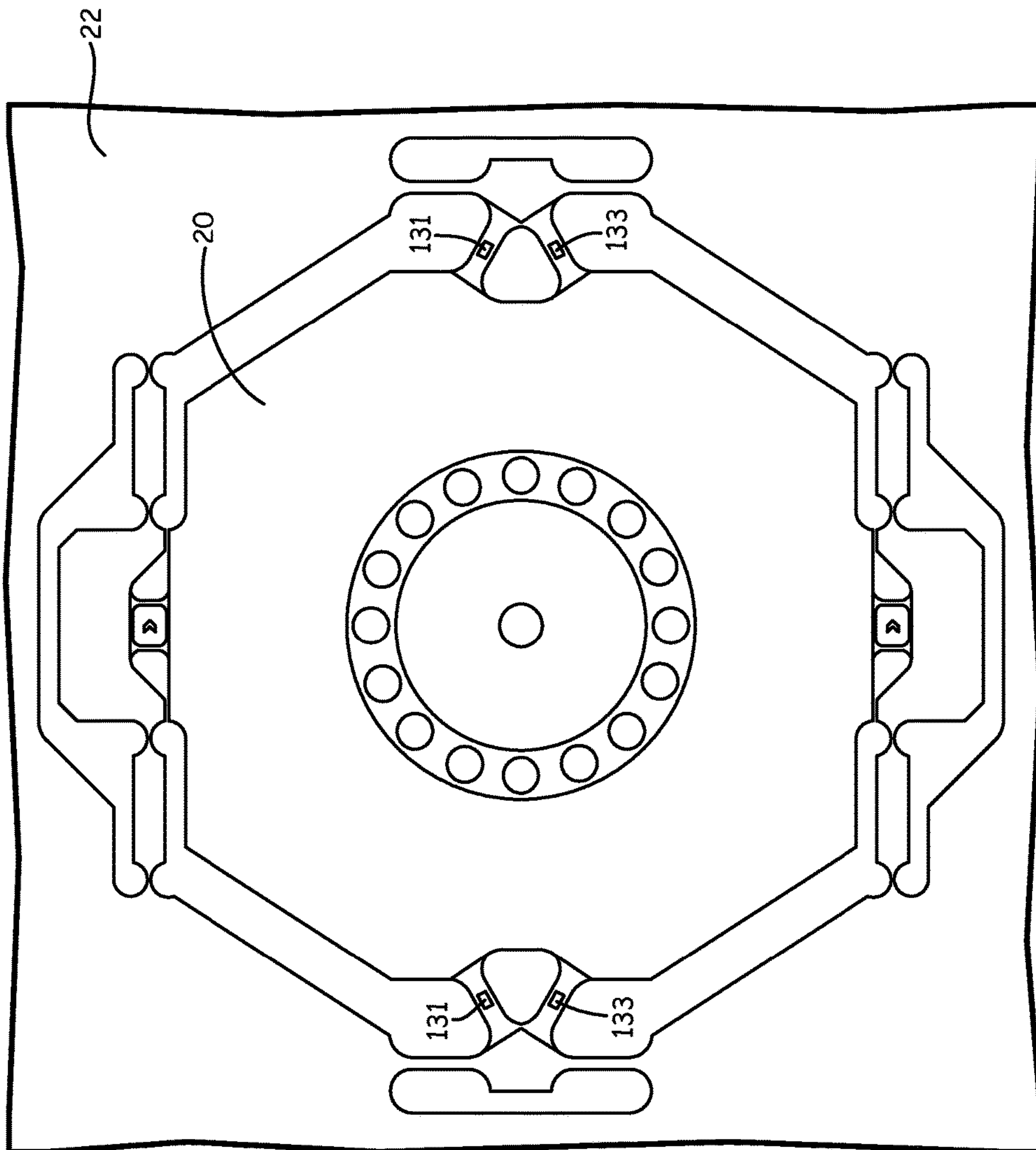
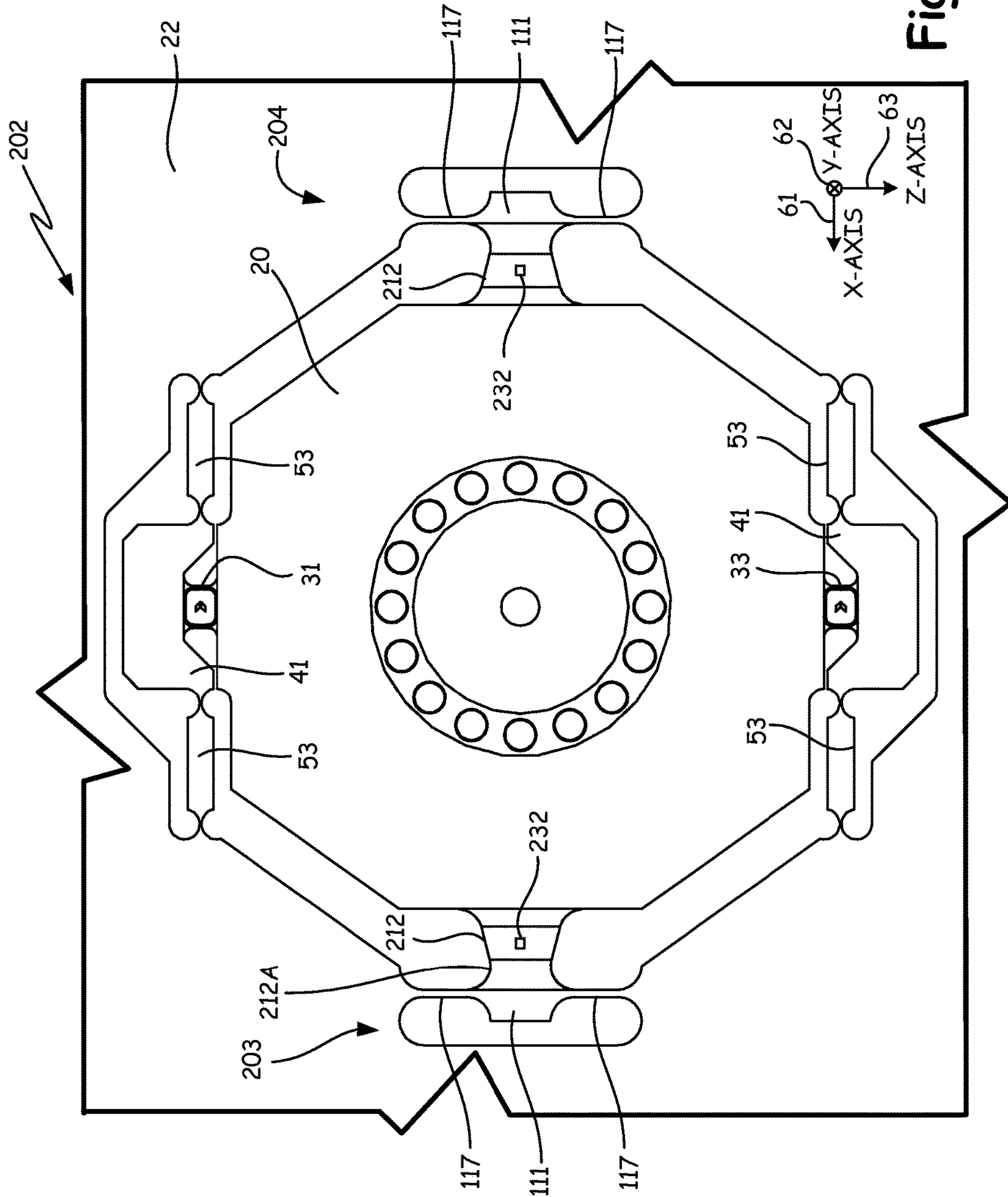


Fig. 12



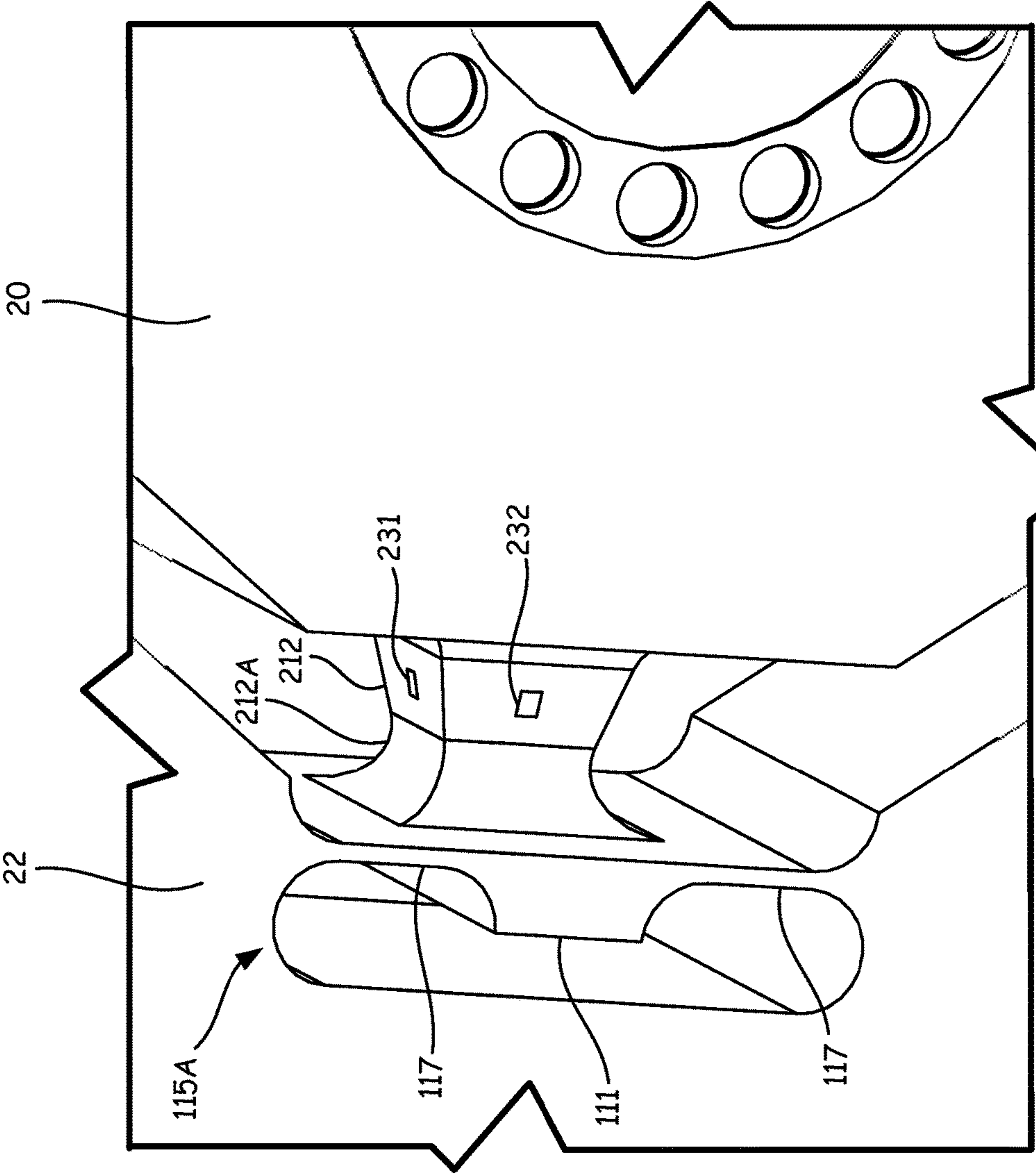


FIG. 15



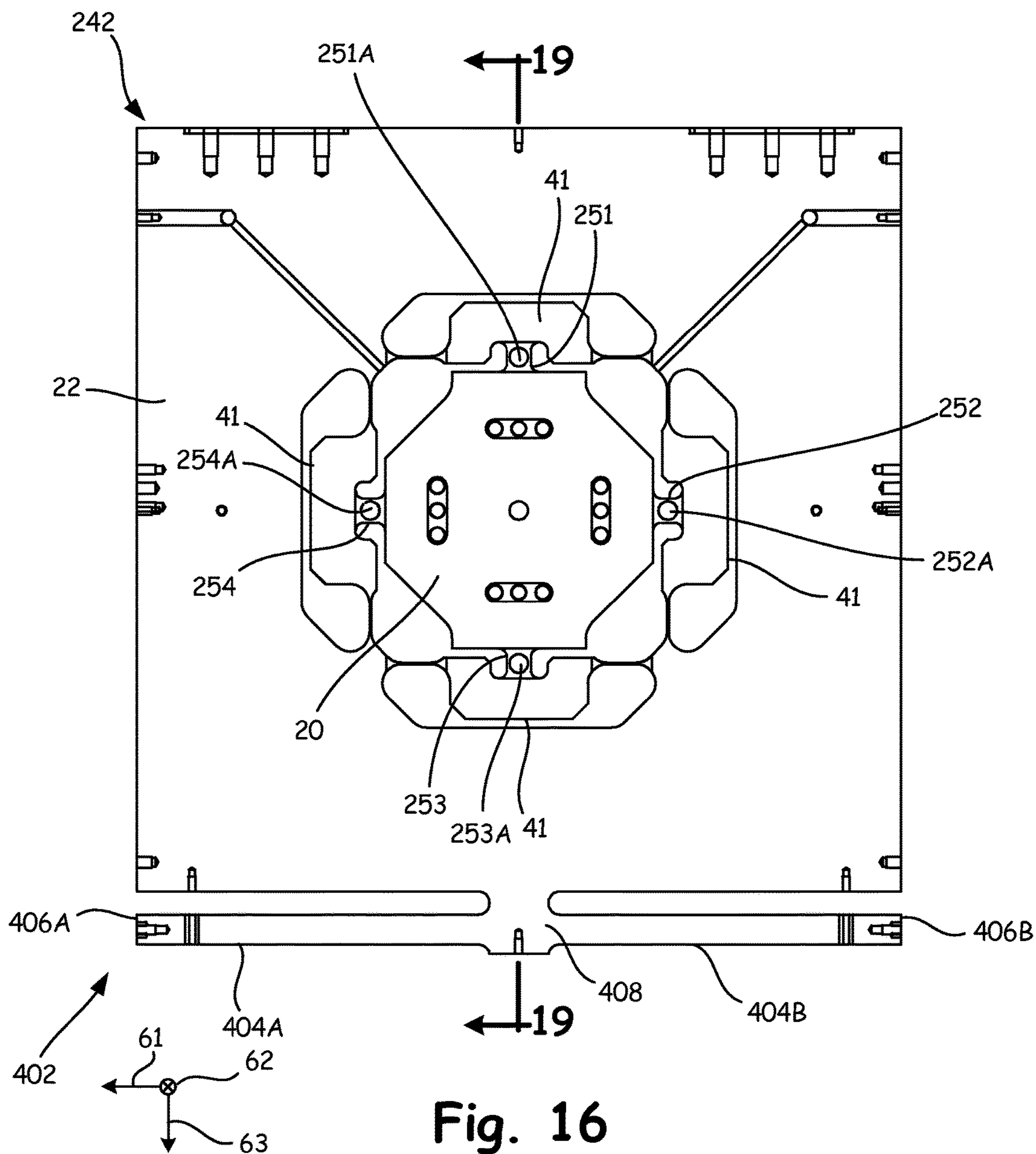


Fig. 16

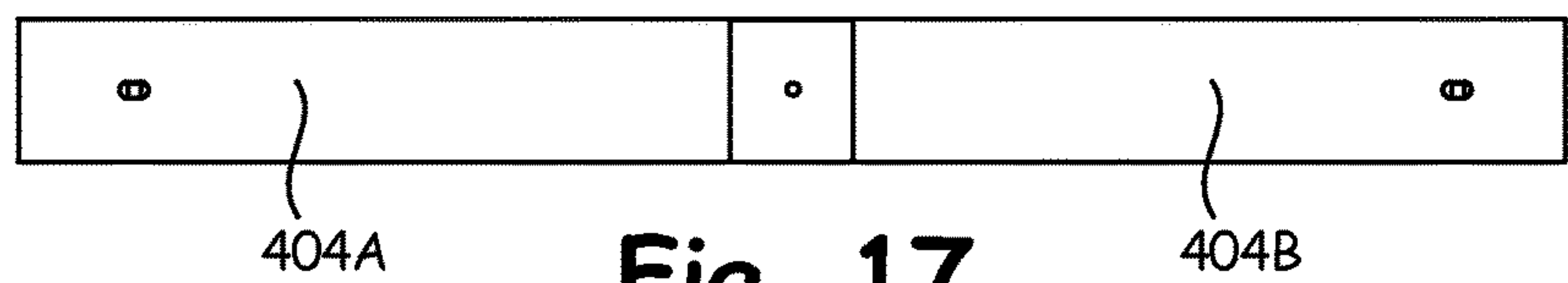


Fig. 17

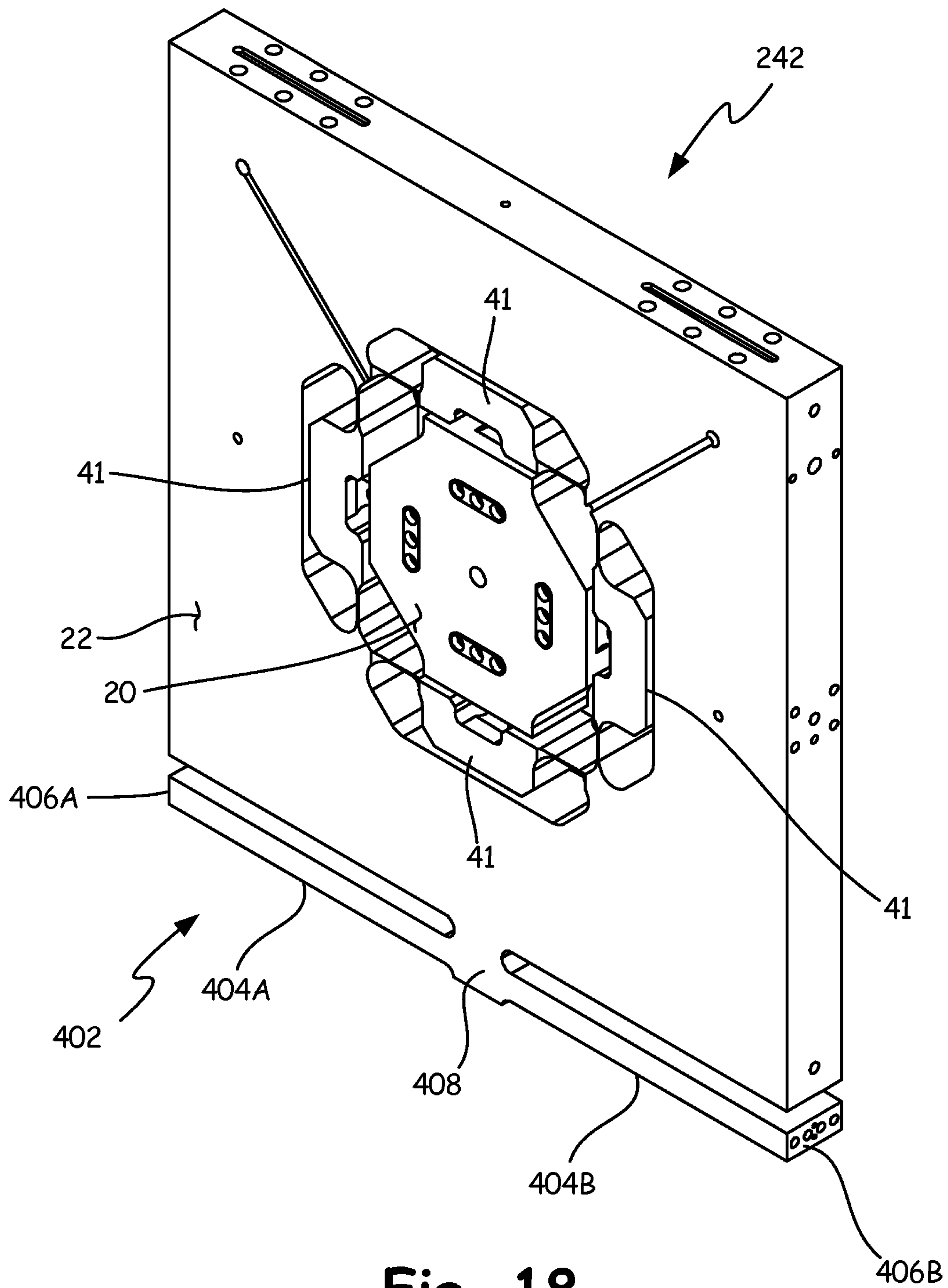


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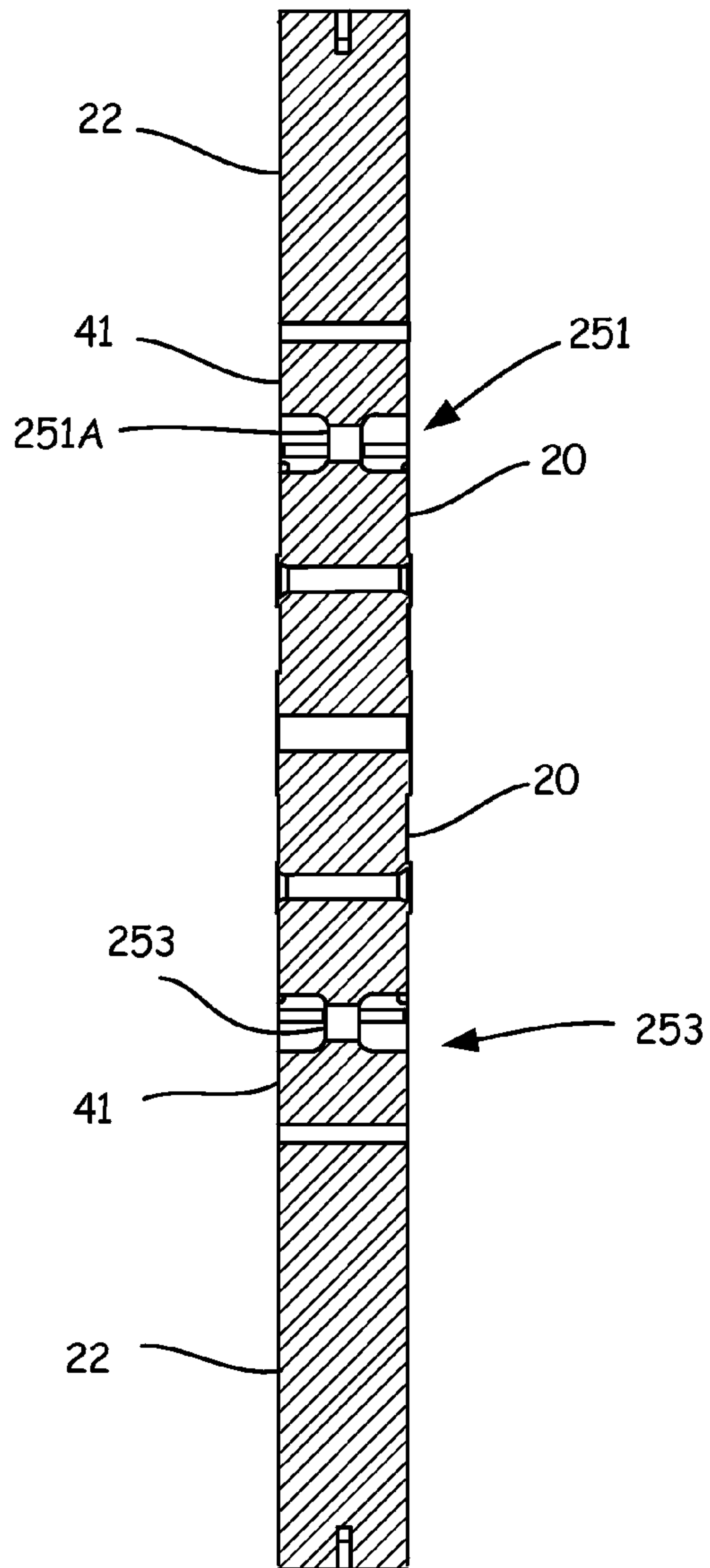


Fig. 19

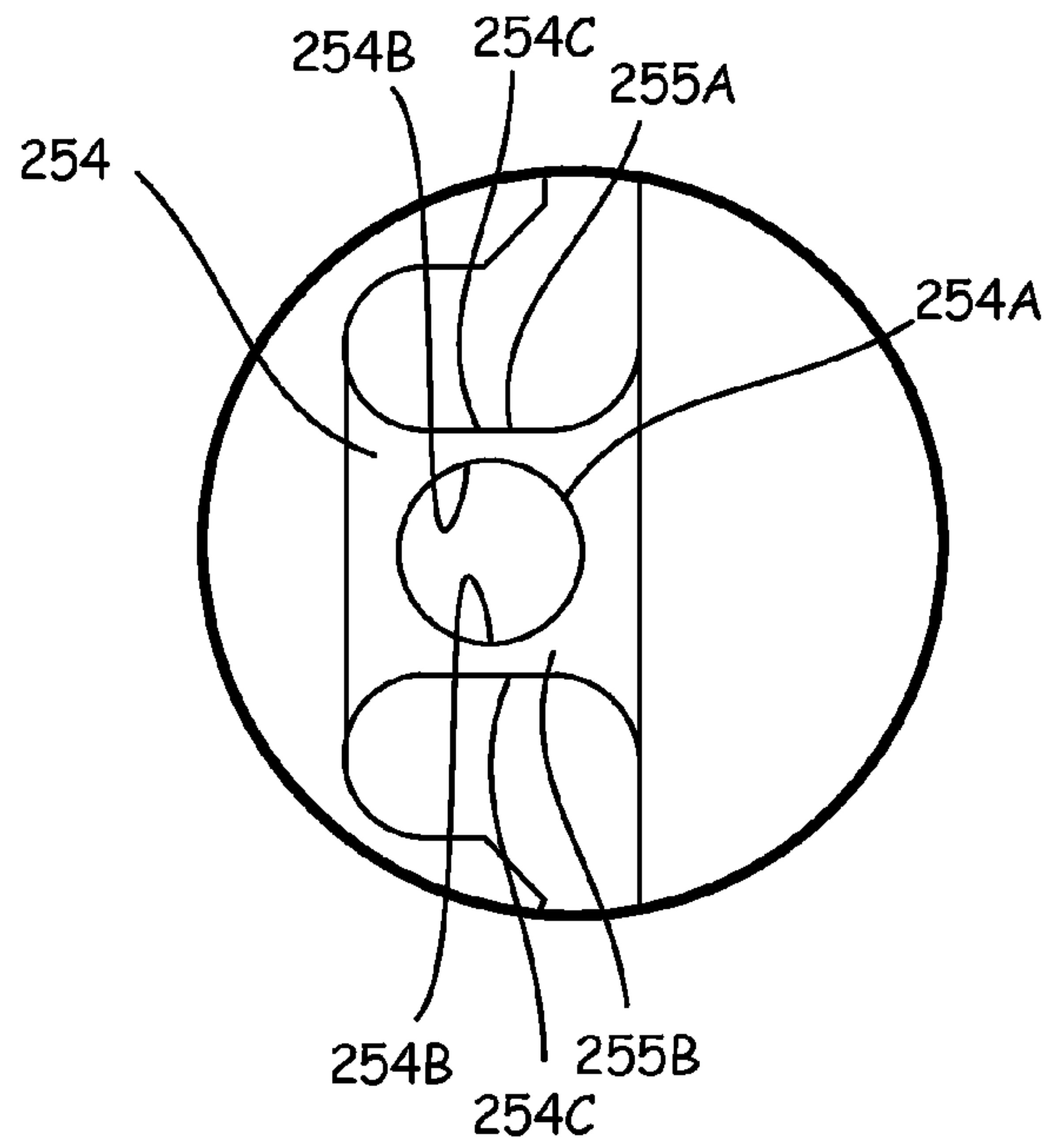


Fig. 20

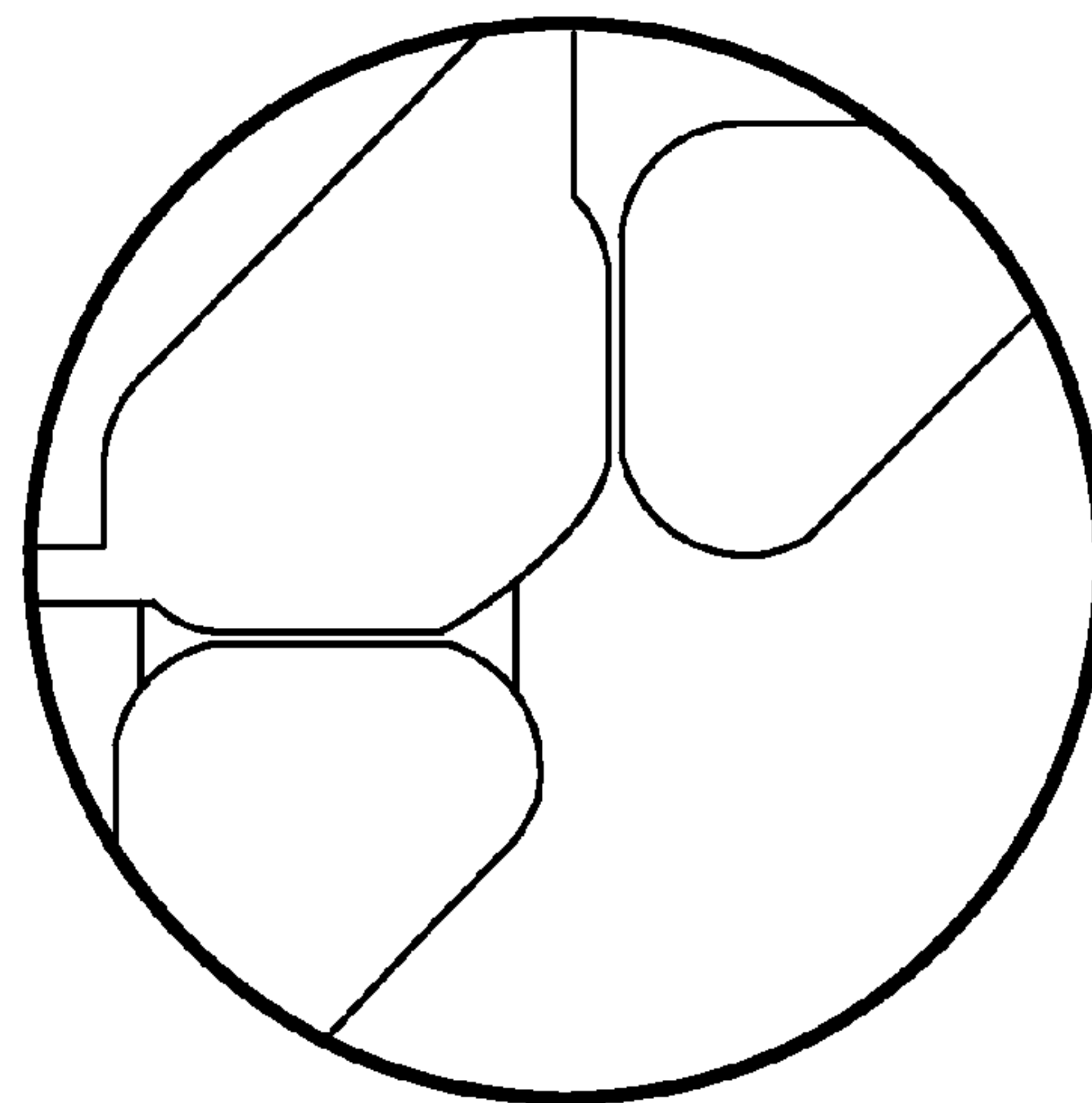


Fig. 21

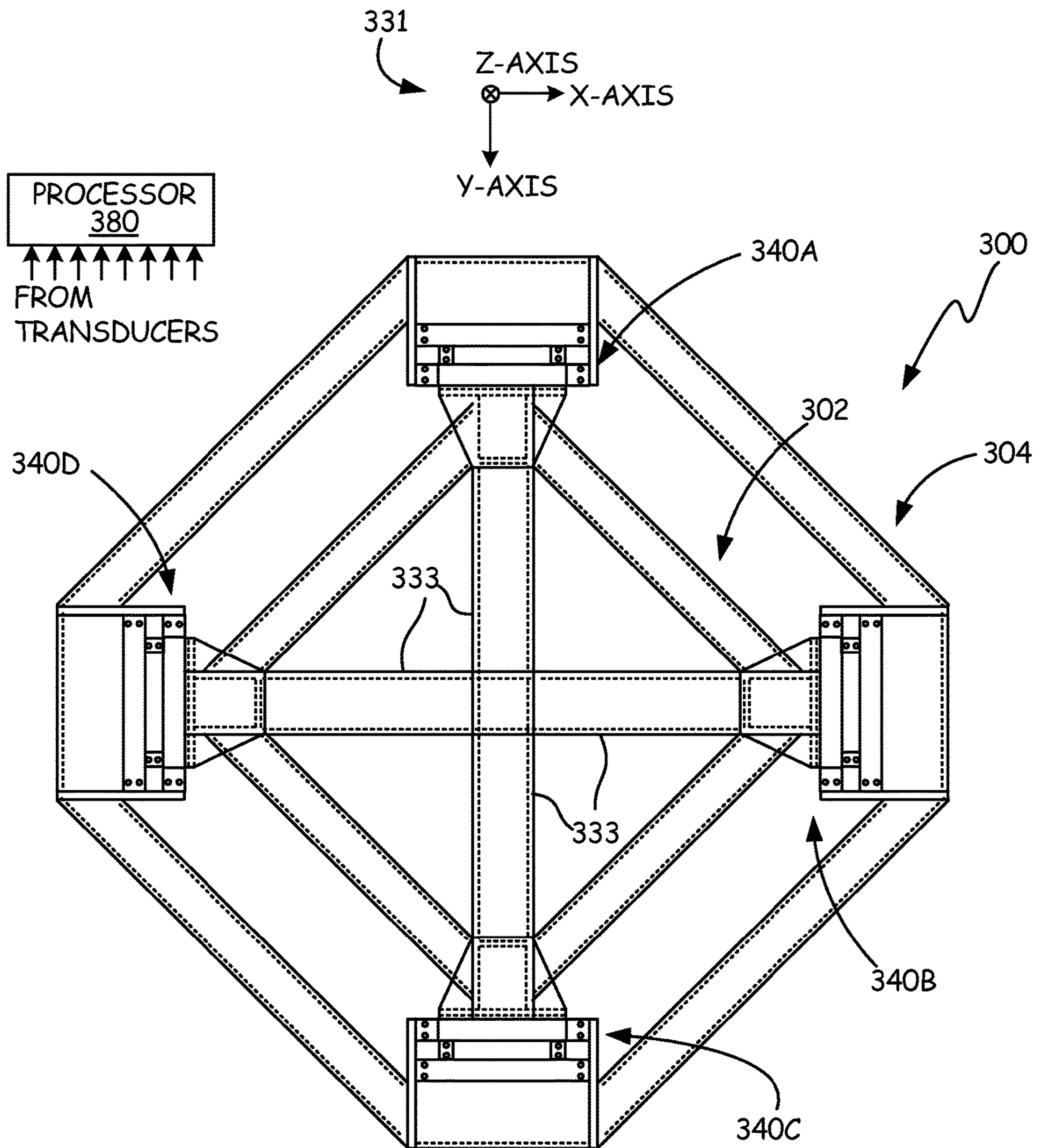


Fig. 22



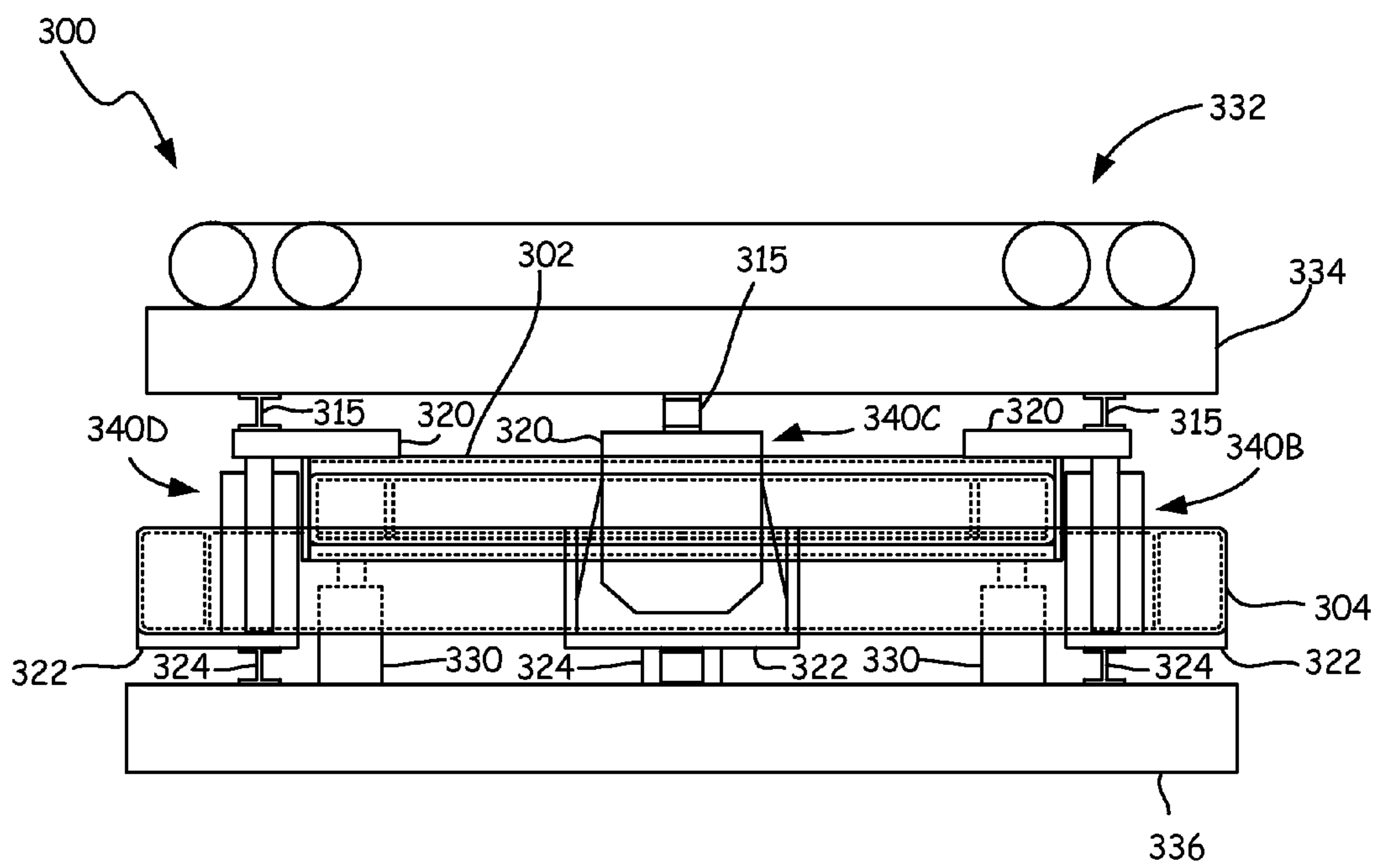


Fig. 23

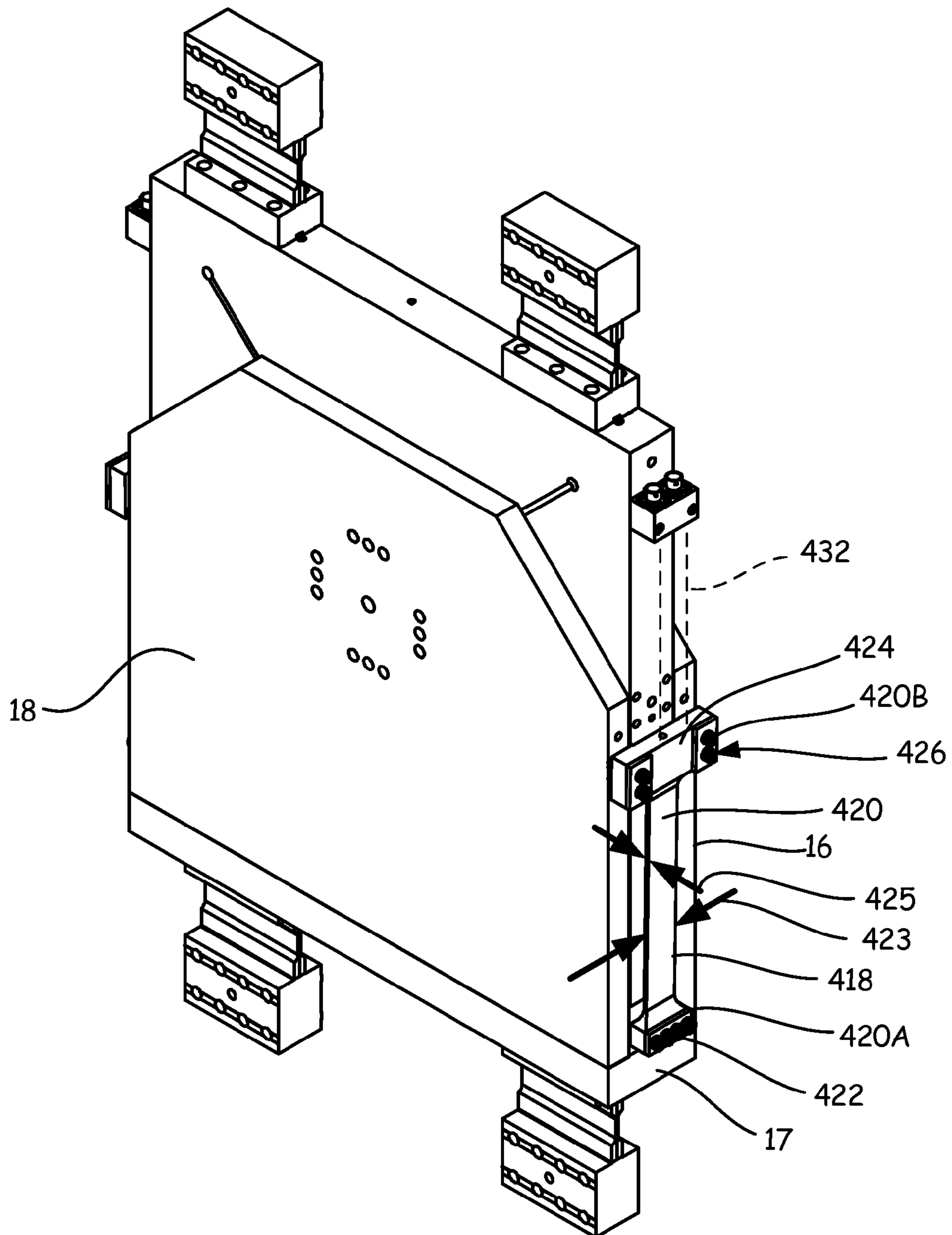


Fig. 24

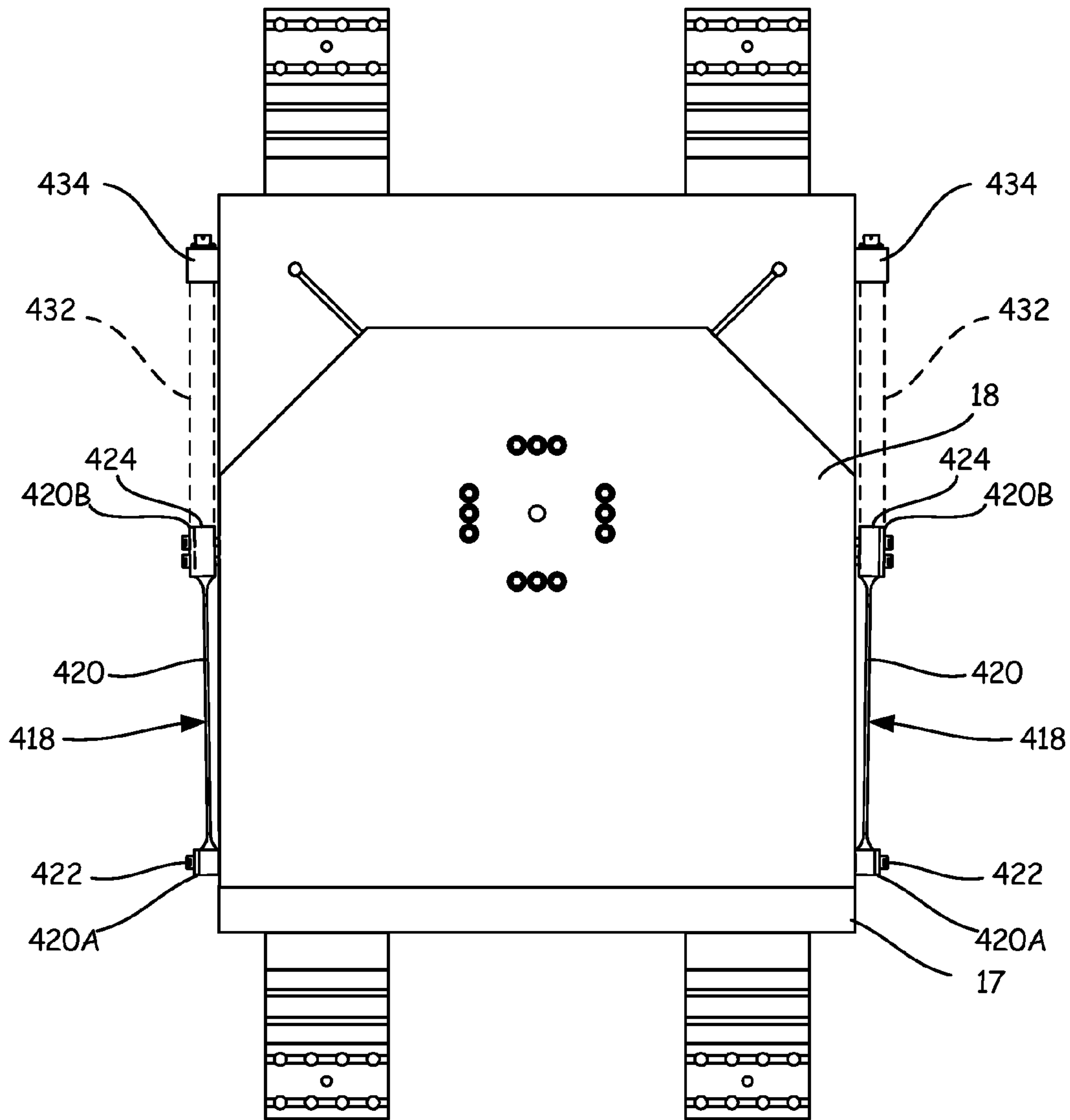


Fig. 25

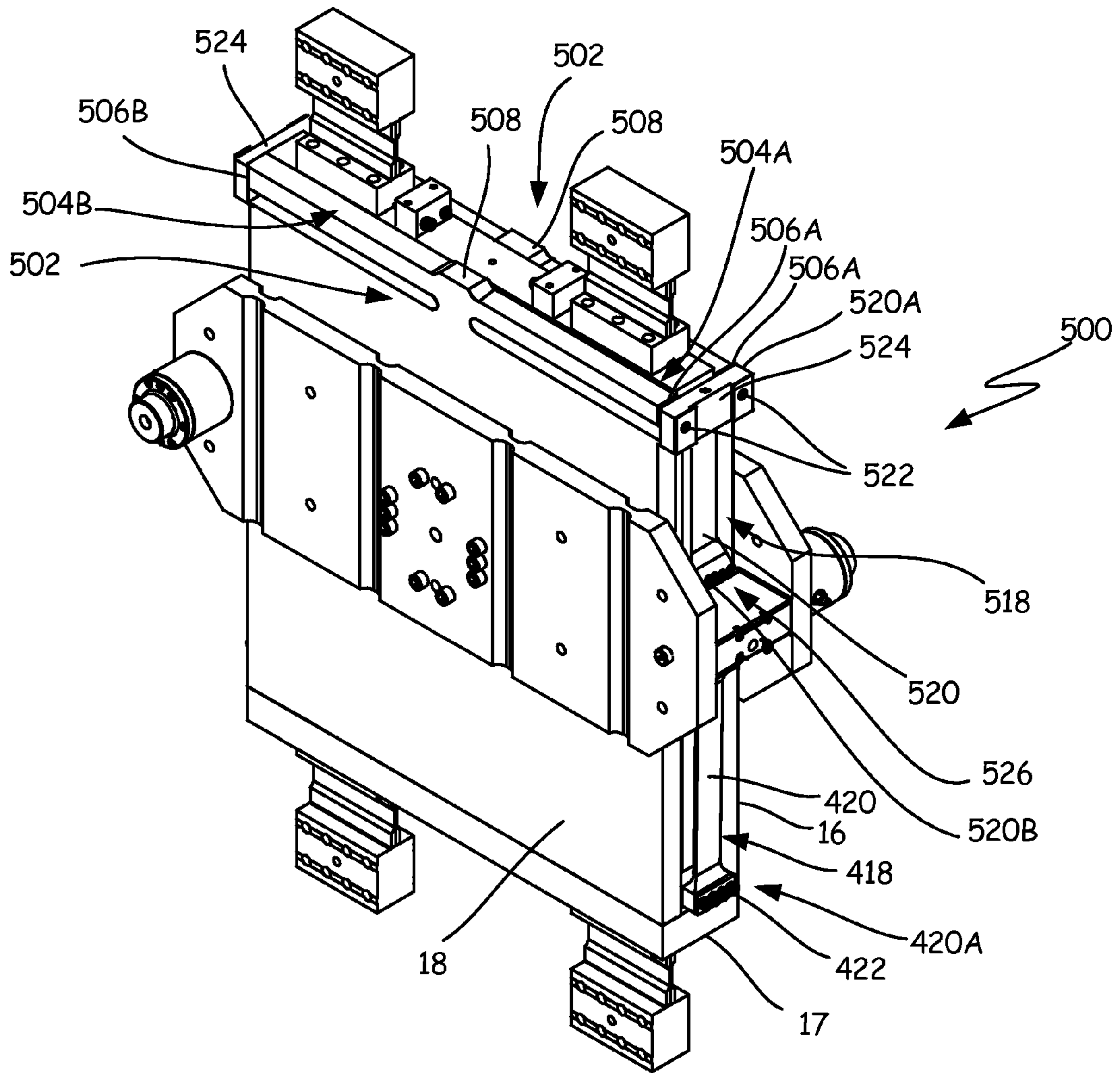


Fig. 26



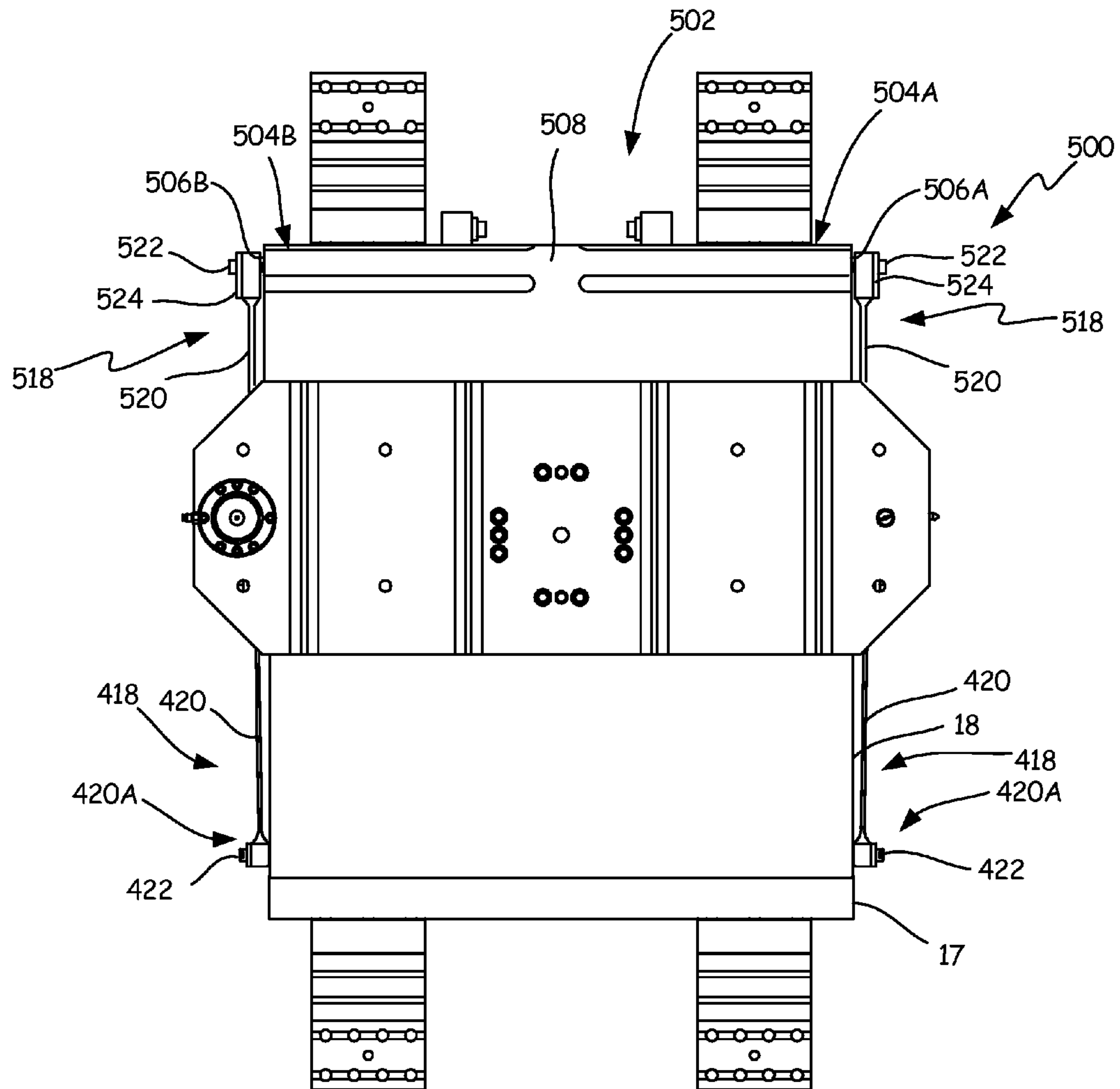


Fig. 27

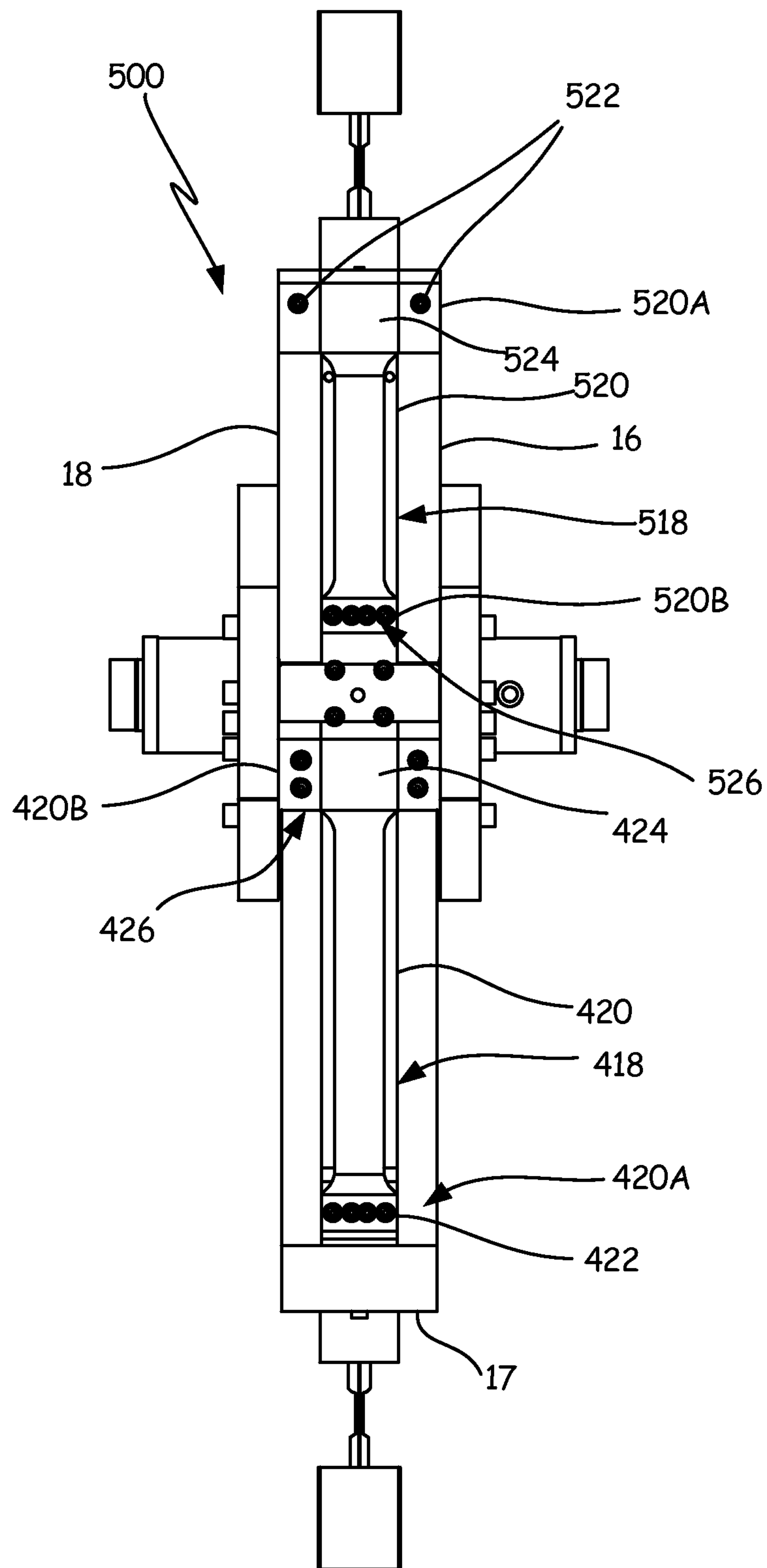


Fig. 28

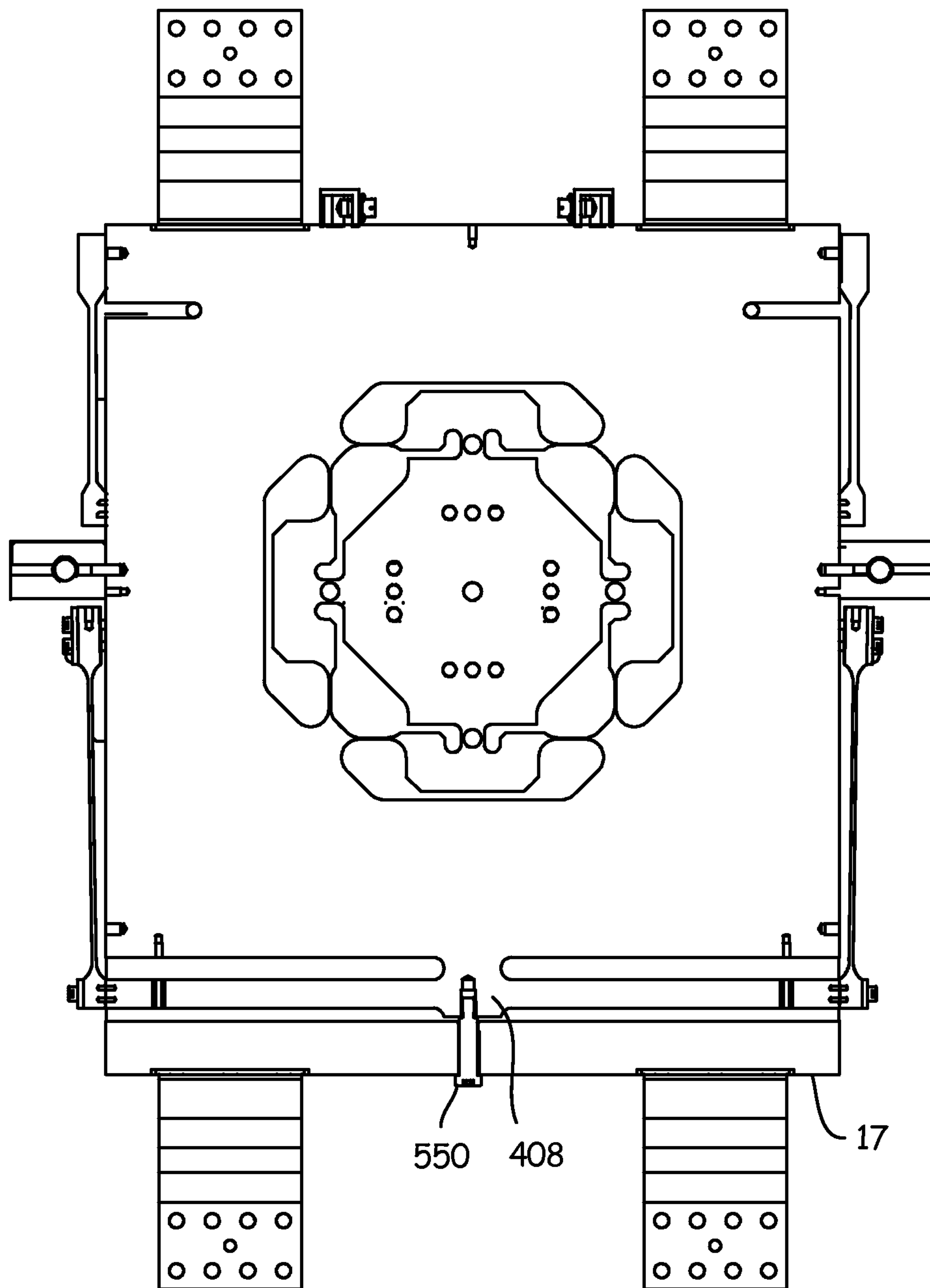


FIG. 29

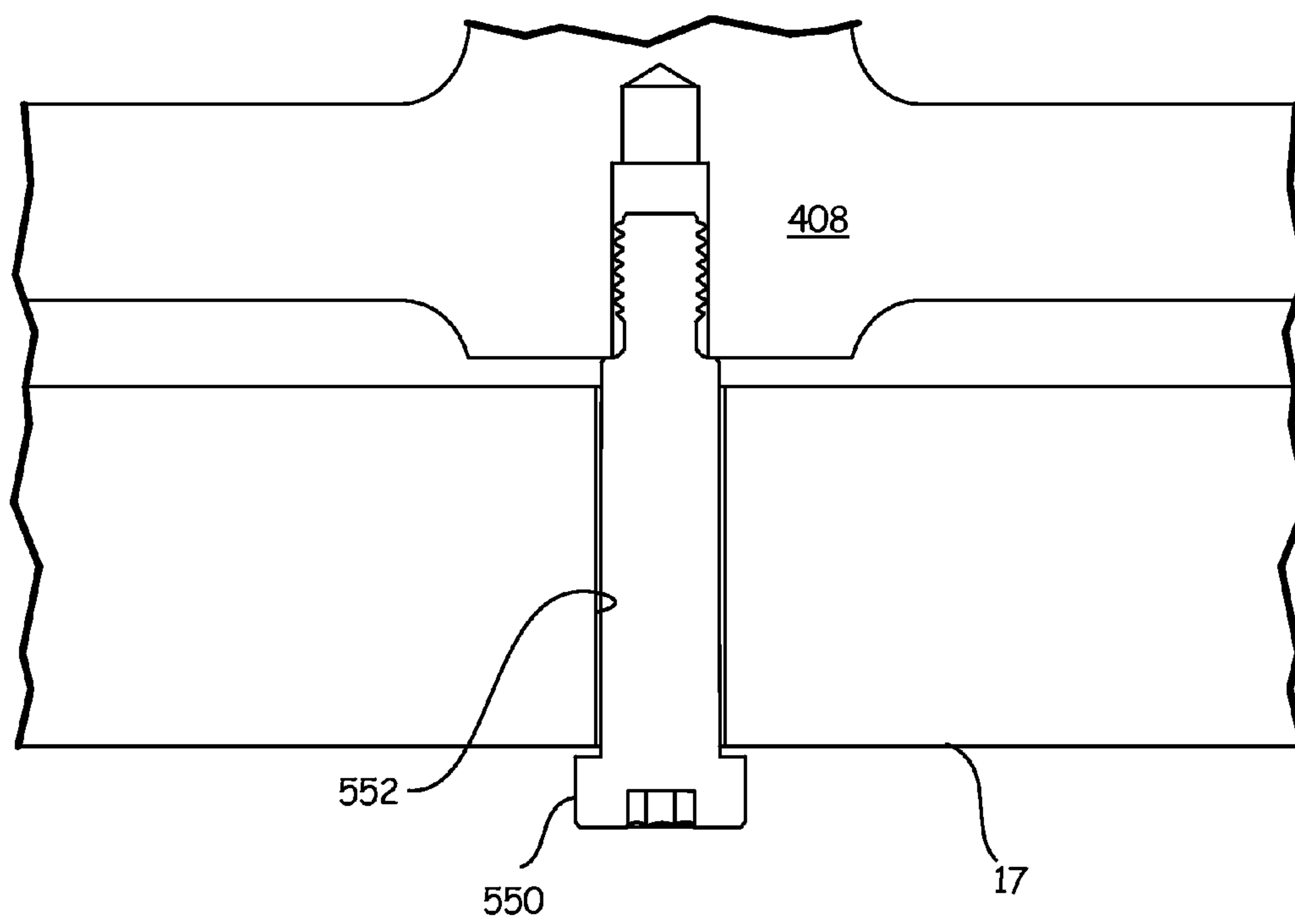


Fig. 30

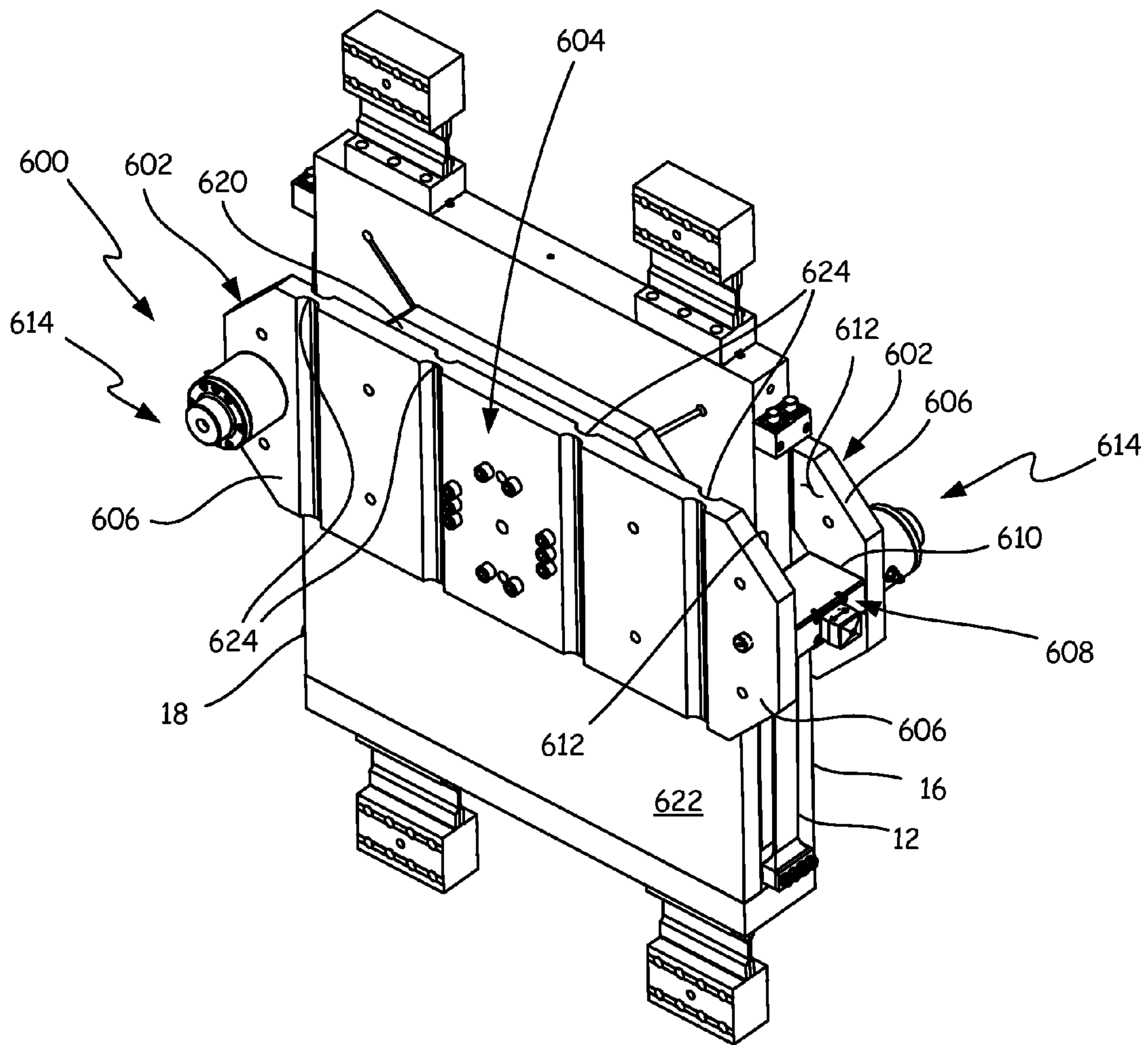


Fig. 31



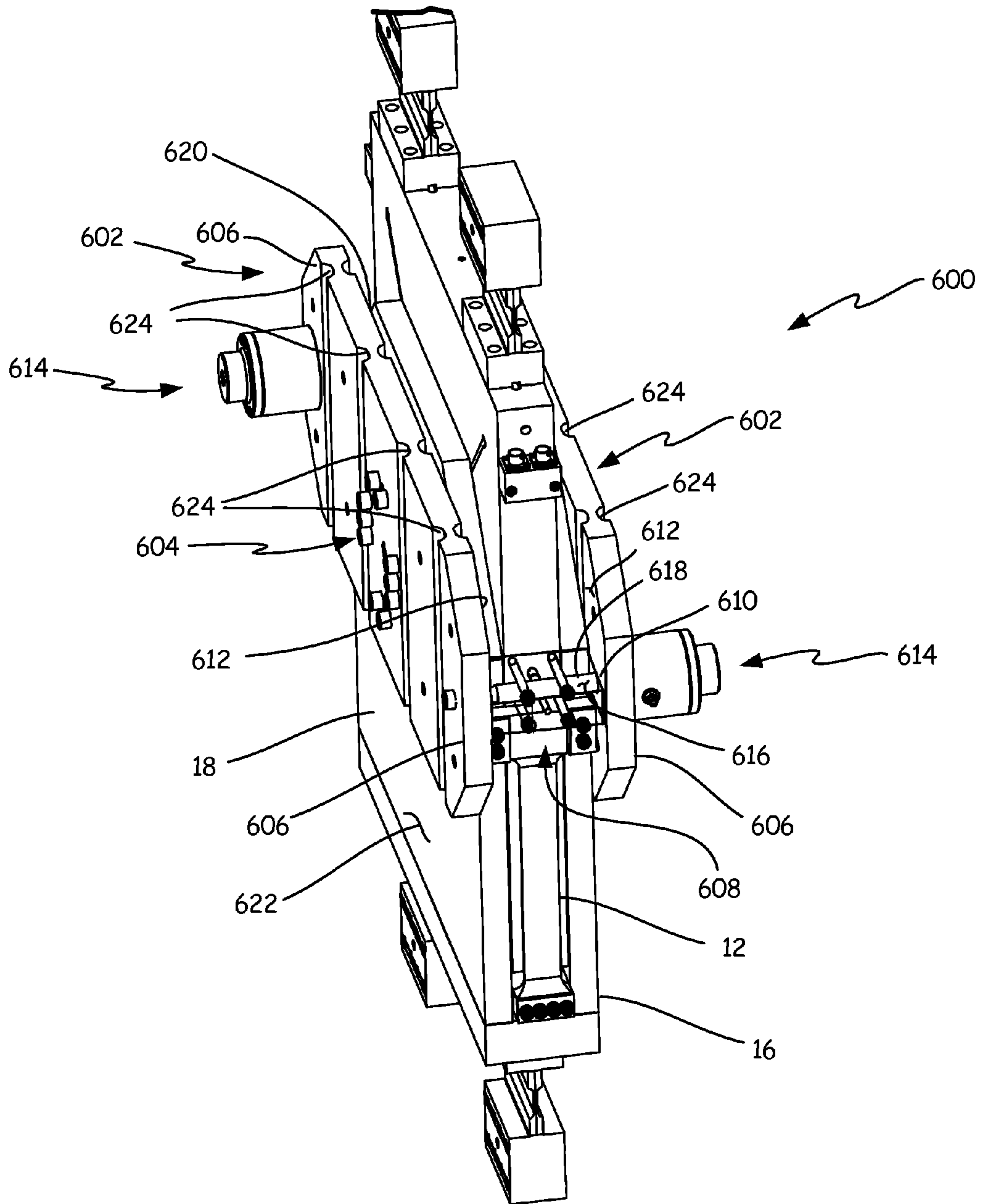


Fig. 32

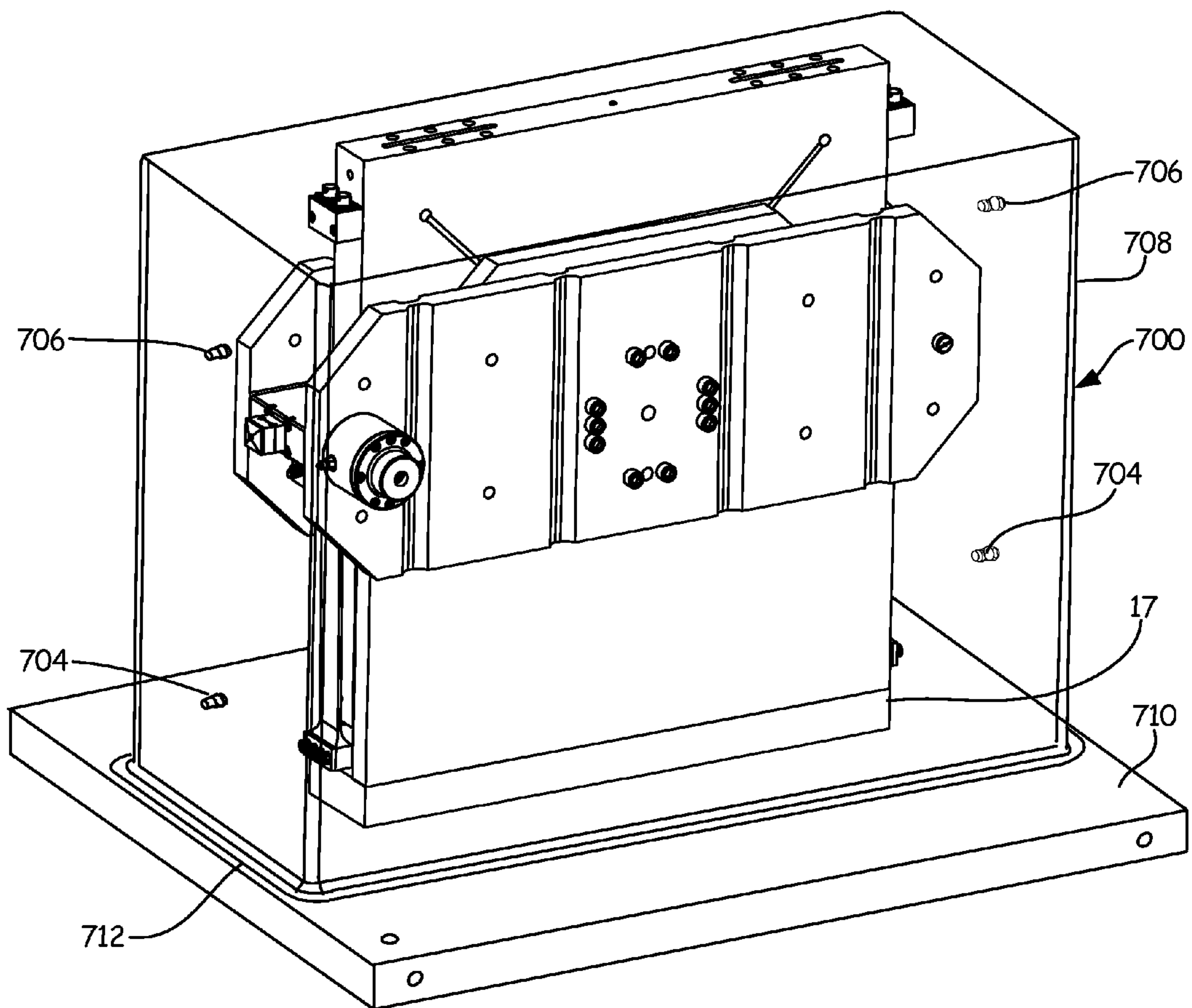


Fig. 33

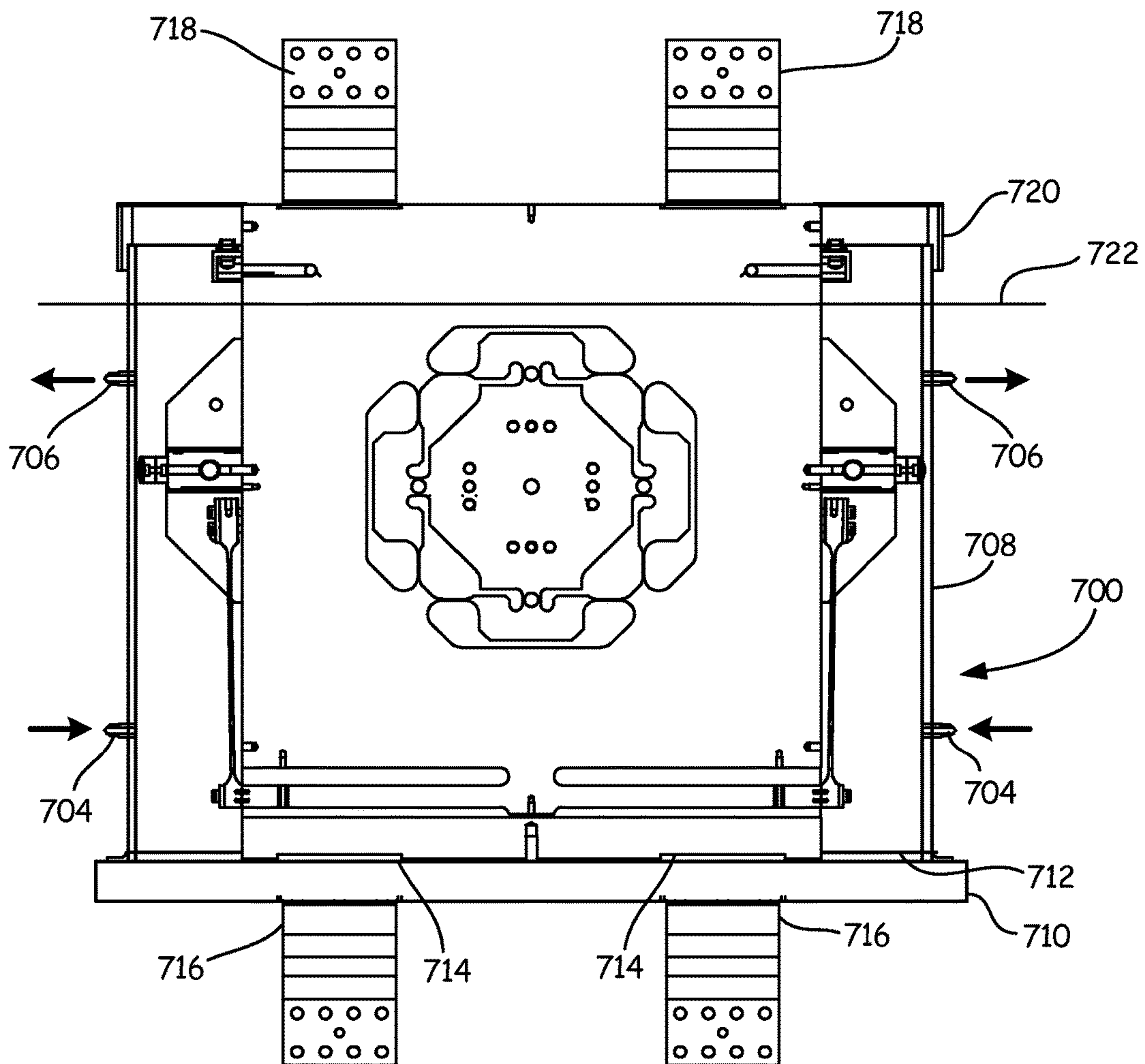


Fig. 34



## TWO-AXIS SENSOR BODY FOR A LOAD TRANSDUCER

### CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional patent application Ser. No. 61/861,221, entitled "TWO-AXIS SENSOR BODY FOR A LOAD TRANSDUCER" filed Aug. 1, 2013, and U.S. Provisional patent application Ser. No. 62/031,642, entitled "TWO-AXIS SENSOR BODY FOR A LOAD TRANSDUCER" filed Jul. 31, 2014, the contents of each of which are incorporated herein by reference in their entireties.

### BACKGROUND OF THE INVENTION

The discussion below is merely provided for general background information and is not intended to be used as an aid in determining the scope of the claimed subject matter.

The present disclosure relates to devices that transmit and measure linear forces along and moments about three orthogonal axes. More particularly, the present disclosure relates to devices that are particularly well suited to measure forces and moments upon a test specimen in a test environment, such as but not limited to in a wind tunnel.

The measurement of loads, both forces and moments, with accuracy and precision is important to many applications. A common use, where several moments and forces need to be measured, is in the testing of specimens in a wind tunnel. Test specimens can be placed on a platform balance located in a pit of the wind tunnel. The platform balance can be arranged to receive a model of a vehicle, a vehicle, or other actual or modeled test specimen.

If the test specimen is a vehicle with wheels, the platform balance can be equipped with a rolling belt to rotate the wheels, which can make a significant improvement in measurement accuracy.

Six components of force and moment act on a test specimen on the platform balance in the wind tunnel. These six components are known as lift force, drag force, side force, pitching moment, yawing moment, and rolling moment. The moments and forces that act on the test specimen are usually resolved into three components of force and three components of moment with transducers that are sensitive to the components. Each of the transducers carries sensors, such as strain gauges, that are connected in combinations that form Wheatstone bridge circuits. By appropriately connecting the sensors, resulting Wheatstone bridge circuit unbalances can be resolved into readings of the three components of force and three components of moment.

Platform balances have a tendency to be susceptible to various physical properties of the test environment that can lead to inaccurate measurements without additional compensation. For example, temperature transients in the wind tunnel can result in thermal expansion of the platform balance that can adversely affect the transducers. In addition, large test specimens are prone to create large thrust loads on the transducers that can cause inaccurate measurements.

### SUMMARY

This Summary and the Abstract herein are provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary and the Abstract are not intended to identify key

features or essential features of the claimed subject matter, nor are they intended to be used as an aid in determining the scope of the claimed subject matter. The claimed subject matter is not limited to implementations that solve any or all disadvantages noted in the Background.

An aspect of the invention provides a transducer body, comprising a support comprising a pair of clevis halves; and a sensor body coupled to each of the clevis halves, wherein the sensor body is disposed between the clevis halves and configured to deflect with forces along two orthogonal axes, wherein the sensor body includes a generally rigid peripheral member disposed about a spaced-apart central hub, the central hub being joined to each of the clevis halves with the peripheral member spaced apart from each clevis half, wherein at least three flexure components couple the peripheral member to the central hub, and wherein the flexure components are spaced-apart from each other at generally equal angle intervals about the central hub; the sensor body further including a flexure assembly for each of said at least some flexure components joining the flexure component to at least one of the central hub and the peripheral member, the flexure assembly being compliant for forces in a radial direction from the central hub through the flexure component and to the peripheral member, wherein each flexure assembly is configured such that forces transferred between central hub and the peripheral member concentrate strain at a midpoint along the length of each corresponding flexure component.

Another aspect of the invention provides a transducer body, comprising a support comprising a pair of clevis halves; a sensor body coupled to each of the clevis halves, wherein the sensor body is disposed between the clevis halves and includes a generally rigid peripheral member disposed about a spaced-apart central hub, the central hub being joined to each of the clevis halves with the peripheral member spaced apart from each clevis half, wherein at least three flexure components couple the peripheral member to the central hub, and wherein the flexure components are spaced-apart from each other at generally equal angle intervals about the central hub; and a biasing assembly connected between the support and the sensor body and configured to provide a bias force between the sensor body and the support.

Another aspect of the invention provides a transducer body, comprising a support comprising a pair of clevis halves; a sensor body coupled to each of the clevis halves, wherein the sensor body is disposed between the clevis halves and includes a generally rigid peripheral member disposed about a spaced-apart central hub, the central hub being joined to each of the clevis halves with the peripheral member spaced apart from each clevis half, wherein at least three flexure components couple the peripheral member to the central hub, and wherein the flexure components are spaced-apart from each other at generally equal angle intervals about the central hub; and a lockup assembly configured to selectively inhibit movement of the sensor body relative to the clevis halves.

Additional aspects of the invention may be combined with any of the above aspects and with each other. Such additional aspects include the following:

An aspect wherein each flexure assembly is configured such that forces transferred between central hub and the peripheral member cause a first force at the connection of the flexure component to the central hub to be equal and opposite to a second force at the connection of the flexure component to the peripheral member, wherein the first and



second force are tangential to the radial direction of each corresponding flexure component.

An aspect wherein said at least some of the flexure components are configured to concentrate strain in shear.

An aspect wherein said at least some of the flexure components are configured to concentrate strain in bending.

An aspect wherein said at least some of the flexure components are configured with a pair of beams.

An aspect wherein the pair of beams of each flexure component of at least some of the flexure components is formed by an aperture.

An aspect wherein the biasing assembly comprises a bias connector configured to operate in tension to provide the bias force.

An aspect wherein the bias connector comprises an elongated strap having a width of the strap greater than a thickness of the strap.

An aspect wherein the biasing assembly comprises a pair of straps provided on opposite portions of the transducer body that are symmetrical.

An aspect wherein the bias connector comprises a flexible member fixedly connected to one of the sensor body or the support.

An aspect wherein the flexible member is integrally formed from a single unitary body of one of the sensor body or the support.

An aspect wherein the biasing assembly comprises a pair of biasing connectors wherein a biasing connector is provided each of opposite portions of the transducer body that are symmetrical.

An aspect wherein the biasing assembly comprises flexible members, a flexible member being fixedly connected to one of the sensor body or the support.

An aspect wherein the flexible members are integrally formed from a single unitary body of one of the sensor body or the support.

An aspect wherein each flexible member comprises a cantilevered beam with one of the biasing connectors connected to one of the flexible members.

An aspect wherein the flexible member is provided on the support.

An aspect wherein a flexible member is provided on each clevis half and a bridging block connects the flexible members together, the bridging block being spaced apart from the sensor body.

An aspect wherein the flexible member is provided on the sensor body.

An aspect wherein the biasing assembly comprises a removable biasing actuator configured to be connected between the sensor body and the support.

An aspect wherein the lockup assembly is configured to inhibit movement of the peripheral member relative to the clevis halves.

An aspect wherein the lockup assembly inhibits movement of the peripheral member by frictional contact.

An aspect wherein the lockup assembly is configured to selectively move portions having engaging surfaces for frictional contact to contact opposed surfaces of the peripheral member, the engaging surfaces and the opposed surfaces being spaced apart from each other to allow forces to be transferred by the flexure components when the lockup assembly is not engaged.

An aspect wherein the lockup assembly comprises a first plate member jointed to a first clevis half and a second plate member jointed to the second clevis half, wherein the engaging surfaces are disposed on the plate members.

An aspect wherein a portion of each plate member is space apart from the associated clevis half.

An aspect wherein when the engaging surface engage the opposed surfaces, the portion of each plate member frictionally engages the associated clevis half.

An aspect and further comprising an actuator configured to selectively bring the engaging surfaces in contact with the opposed surfaces and also bring the portions of each plate member into contact with each associated clevis half.

An aspect wherein major surfaces of the portions of the plate members engage major surfaces of the associated clevis halves.

An aspect wherein the engaging surfaces are on the plate members, and wherein each plate member comprises a hinges and a link portion between the hinges, the link portion connecting portions of the plate members having the engaging surfaces with portions of the plate members having the major surfaces.

An aspect wherein the actuator is operably mounted to the portions of the plate members having the engaging surfaces, and wherein the actuator includes a pull rod to selectively pull the pull rod so as to bring the engaging surfaces in contact with the opposed surfaces.

An aspect wherein the pull rod extends through a bore opening to one of the opposed surfaces, the pull rod being spaced apart from inner surfaces of the bore at least when the actuator is not pulling on the pull rod to bring the engaging surfaces in contact with the opposed surfaces.

A platform balance may be provided in another aspect with transducer bodies and aspects as shown and described.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevation view of a transducer body according to an embodiment of the present disclosure;

FIG. 2 is a perspective view of a sensor body according to an embodiment of the present disclosure;

FIG. 3 is a front elevation view of the sensor body of FIG. 2;

FIG. 4 is a view of the sensor body taken along lines 4-4 of FIG. 3;

FIG. 5 is a close-up view of a portion of the sensor body of FIG. 3;

FIG. 6 is a close-up view of a portion of the cut away view of FIG. 4;

FIG. 7 is a circuit diagram of a Wheatstone bridge for the sensor elements of FIG. 2;

FIG. 8 is a close up view of a portion of the sensor body of FIG. 2;

FIG. 9 is a front elevation view of a sensor body according to another embodiment of the present disclosure;

FIG. 10 is a perspective view of the sensor body of FIG. 9;

FIG. 11 is a close up view of a portion of the sensor body of FIG. 10;

FIG. 12 is a front elevation view showing locations of sensor elements on the sensor body of FIG. 9;

FIG. 13 is a circuit diagram of a Wheatstone bridge for the sensor elements of FIG. 9;

FIG. 14 is a front elevation view of a sensor body according to another embodiment of the present disclosure;

FIG. 15 is a close up view of a flexure element of the sensor body of the FIG. 14;

FIG. 16 is a front elevation view of yet another sensor body according to another embodiment of the present disclosure;

FIG. 17 is a bottom view of the sensor body of FIG. 16;



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FIG. 18 is a perspective view of the sensor body of FIG. 16;

FIG. 19 is a cut away view along lines 19-19 of FIG. 16;

FIG. 20 is a close up view of a flexure element of FIG. 16;

FIG. 21 is a close up view of an alternate flexure element according to another embodiment of the present disclosure;

FIG. 22 is a top view of a platform balance according to an embodiment of the present disclosure;

FIG. 23 is a side elevation view of the platform balance of FIG. 22;

FIG. 24 is a perspective view of a transducer body according to another embodiment of the present disclosure;

FIG. 25 is a front elevation view of the transducer body of FIG. 24;

FIG. 26 is a perspective view of a transducer body according to another embodiment of the present disclosure;

FIG. 27 is a front elevation view of the assembly of FIG. 26;

FIG. 28 is a right side elevation of the assembly of FIG. 26;

FIG. 29 is a cut away view showing a front elevation of a sensor body in place on the assembly of FIG. 26;

FIG. 30 is a close up view of a portion of FIG. 29;

FIG. 31 is a perspective view of a clamp assembly in place on a transducer body according to another embodiment of the present disclosure;

FIG. 32 is a close up and partial cut away view of a portion of the assembly of FIG. 31;

FIG. 33 is a perspective view of a transducer body in a fluid recirculating bath assembly according to another embodiment of the present disclosure; and

FIG. 34 is a front elevation view of the assembly of FIG. 33.

#### DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

Referring to FIG. 1, a transducer assembly is illustrated at 10. The transducer assembly 10 includes a sensor body 12 and a clevis assembly 14. The clevis assembly 14 includes a first clevis half 16 and a second clevis half 18. The clevis halves 16 and 18 are joined together at one end with a connecting member 17. The sensor body 12 is disposed between the clevis halves 16 and 18, where the sensor body 12 and clevis halves 16 and 18 are joined together with a suitable fastener assembly. In the embodiment illustrated, the sensor body 12 includes a plurality of apertures 15 (FIG. 2) through which bolts or threaded rods can extend there-through so as to secure each of the clevis halves 16 and 18 (having similar aligned apertures) to opposite sides of the sensor body 12. In another embodiment, a bolt or threaded rod can extend through aligned bores 19, 21, and 23 (FIG. 1) in each of the clevis halves 16 and 18 and sensor body 12. A nut (not shown) can be provided on one end of the rod and a super nut can be threaded upon an opposite end. A plurality of set screws extends through apertures in the super nut to engage in end of one of the clevis halves 16 or 18. This fastening technique is described in U.S. Pat. No. 7,788,984, which is incorporated herein by reference in its entirety.

It should be noted that although portions of the clevis 16 and 18 will engage or contact a center portion of the sensor body 12, gaps are provided between each of the clevis halves 16 and 18 and the sensor body 12 so as to allow portions of the sensor body 12 to move relative to the clevis halves 16 and 18. In the embodiment illustrated, projecting center portions 15A and 15B provided on each side of the sensor body 12 ensure contact of the clevis halves 16, 18 only with

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the center portions 15A and 15B (FIGS. 3 and 4), thereby maintaining the gaps as described above.

Referring to FIGS. 2-6, the sensor body 12 is preferably integral, being formed of a signal unitary block of material.

The sensor body 12 includes a rigid central hub 20 upon which the surfaces 15A and 15B reside, and a rigid perimeter body 22 that is concentric with or disposed about central hub 20. A plurality of flexure structures 24 join the central hub 20 to the perimeter body 22. In the embodiment illustrated, the plurality of flexure structures 24 comprise four components 31, 32, 33 and 34. Each of the components 31-34 extend radially from the central hub 20 along corresponding longitudinal axis 31A, 32A, 33A and 34A. Preferably, axis 31A is aligned with axis 33A, while axis 32A is aligned with axis 34A. In addition, axes 31A and 33A are perpendicular to axes 32A and 34A. Although illustrated wherein the plurality of flexure components equals four, it should be understood that any number of components three or more can be used to join the central hub 20 to perimeter body 22. Preferably, the flexure components 31-34 are spaced at equal angular intervals about a central axis indicated at 35.

Referring to flexure component 31 by way of example, an intermediate member 41 is integral with, being formed from the unitary block of material, or otherwise connected to flexure component 31 at an end opposite central hub 20. Intermediate member 41 is preferably symmetric with respect to flexure component 31 or longitudinal axis 31A having side portions 41A and 41B on opposite sides of flexure component 31 or longitudinal axis 31A. Each side portion 41A, 41B is connected to perimeter body 22 through a flexure assembly 51A, 51B, respectively. Referring to flexure assembly 51A by way of example, each of the flexure assemblies 51A and 51B, in the embodiment illustrated, include a rigid connecting member 55. The connecting member 53 is connected or joined to one of the side portions 41A, 41B through a thin flexible web 55. At an end opposite the intermediate member 41, the connecting member 55 is connected to perimeter body 22 through a thin web 57. It should be noted that the webs 55 and 57 are relatively wide being, for example, similar to the width or thickness of the perimeter body 22; however, each of the webs 55 and 57 are thin in a direction normal to the width of the perimeter body 22. The orientation of each of the webs 55 and 57 connecting the intermediate member 41 to the perimeter body 22 are oriented perpendicular to the flexure component associated with each intermediate number 41. In other words, each of the connecting webs 55 and 57 are relatively wide in a direction parallel to the central axis 35, but thin in a cross-section perpendicular to axis 35. In contrast, each of the flexure components 31-34 are thin in a direction parallel to the central axis 35 and relatively wide in a cross-section perpendicular to the axis 35. Given this construction, the connecting webs 55 and 57 are compliant for forces along the longitudinal axis of the flexure component to which it is connected, but stiff for an axis orthogonal to the axis of the flexure component to which it is associated with, and the axis orthogonal to the foregoing axes (or the axis parallel to the central axis 35).

In the exemplary embodiment comprising four orthogonal flexure components 31-34, the flexure components 31-34 operate in pairs for forces along an axis that is orthogonal to the longitudinal axes of each pair of flexure components (31,33 and 32,34) and orthogonal to the central axis 35. In particular, flexure components 31 and 33 transfer forces between the central body 20 and the perimeter body 22 for forces along an axis 61 (wherein connecting webs 55 and 57 associated flexure components 32 and 34 are compliant in



this direction), while flexure components 32 and 34 transfer forces between the central body 20 and the perimeter body 22 for forces along an axis 63 (wherein connecting webs 55 and 57 associated flexure components 31 and 33 are compliant in this direction).

It should be noted that the flexure assemblies 51A and 51B (herein by example connecting member 53 and connecting webs 55, 57) associated with each flexure component 31-34 (on opposite sides of the flexure component) are disposed so as to coincide at least approximately with a midpoint along the length of the corresponding flexure component. Referring to the enlarged view of FIG. 5 a midpoint of the longitudinal length of the flexure component 31 is indicated at 66. The flexure assemblies 51A, 51B on opposite sides of the flexure component 31 (herein comprising connecting webs 55 and 57), are orthogonal to the associated flexure component in a planar sense, but are configured or disposed so as to be approximately inline with the midpoint 66 as represented by dashed line 68, or substantially proximate to the midpoint 66. In other words the web(s) of the flexure assemblies 51A, 51B on each side of the flexure component they are associated with can be defined by corresponding planes, the planes of which are orthogonal to a plane representing the flexure component. Orientation of the connecting web(s) of the flexure assemblies 51A, 51B relative to the associated flexure component at the midpoint 66 causes forces to be transferred through the center of the length of the flexure component which allows the component to be very stiff with most deflection due to strain deflection and not bending. Since the flexure component is very stiff it has a good frequency response with excellent resolution. Since each of the flexure components 31-34 and associated flexure assemblies 51A, 51B are connected in the manner described above about center axis 35, the sensor body 12 includes flexure elements (flexure components 31-34) that can be used to sense forces with respect to two orthogonal axes 61, 63 that can carry high loads with high resolution.

In one embodiment, each flexure assembly is configured such that forces transferred between central hub 20 and the peripheral member 22 cause a first force at the connection of the flexure component to the central hub 20 to be equal and opposite to a second force at the connection of the flexure component to the peripheral member 22, wherein the first and second force are tangential to the radial direction of each corresponding flexure component.

It should be noted one aspect of the invention is use of the flexure assemblies being configured such that on each side of the flexure component they are connected to provide compliance in a direction of the longitudinal length of the flexure component from the hub to the outer perimeter. The flexible elements of the flexure assemblies are defined by aligned corresponding planes, the planes of which are orthogonal to the direction of compliance and coincide at least approximately with a midpoint along the length of the corresponding flexure component. Although various embodiments of flexure components such as components 31-34 have and will be described, these specific structures should not be considered the only components that can be used, but rather other flexure components can be used.

In one embodiment each of the flexure components 31-34 includes sensor elements to measure shear deflection or strain therein. The sensing elements can take any number of forms known to those skilled in the art, including electrically and optically based sensor elements to name just a few. In the embodiment illustrated, strain gauges are connected in a Wheatstone bridge with strain gauge elements placed on

both sides of the flexure component on the principle stress axis. Referring to the enlarged view of FIG. 5 and the circuit diagram of FIG. 7, the Wheatstone bridge 70 includes sensor elements 71 and 72, on one side of the flexure component, while on a side opposite of the flexure component that is shown in FIG. 5, sensor elements and 73 and 74 (shown with dashed lines) are affixed to the flexure component.

It should be noted in the embodiment illustrated, each of the flexure components 31-34 are relatively thin in a direction parallel to central axis 35. However, it should be noted, that the component is not thin in this direction in order to necessarily provide compliance but rather, the thickness of the flexure components are minimized in order to obtain a high output signal (maximize deflection) and a higher signal to noise ratio. In yet an alternative embodiment illustrated in FIG. 8, the flexure component 31 includes a sensing portion 80 upon where the sensor elements 71 and 72 are disposed (sensor elements 73 and 74 being on the opposite side of sensing portion 80) and portions 82A and 82B that are on opposite sides of sensor portion 80 and are of greater thickness in order to provide greater stiffness in the direction parallel to the central axis 35, while still maintaining required sensitivity in the axis of measurement.

Another sensor body is indicated at 102 at FIGS. 9-13, which can be used in place of the sensor body 12, described above, in one exemplary embodiment. The sensor body 102 has elements similar in function to that described above with respect to sensor body 12 and has such similar components are identified with the same reference numbers. As illustrated, the sensor body 102 includes flexure components 31 and 33, intermediate members 41, connecting members 53 and connecting webs 55-57. The flexure components 31 and 33 measure forces between the central body 20 and the perimeter body 22 for forces in a direction parallel to axis 61. Sensor body 102 however includes flexure structures 102 and 104 to transfer forces between the central body 20 and the perimeter body 22 along axis 63. The flexure structures 103 and 104 are designed to be substantially stiffer than the flexure components 31 and 33 so as to transfer substantially larger forces between the central body 20 and the perimeter body 22.

Referring to flexure structure 103 by way of example, each of the flexure structures 103 and 104 include two flexure components 112A and 112B extending from the central body 20 to an intermediate member 111. As illustrated, the flexure components 112A, 112B each have a longitudinal axis indicated at 113A and 113B wherein an acute angle 116 is formed between the axes 113A, 113B. In the embodiment illustrated, the flexure components 112A, 112B are oriented so as to converge in a direction toward the intermediate member 111; however, in an alternative embodiment, if desired, an acute angle can be formed between the flexure components with convergence toward the central body 20 rather than the intermediate member 111.

The intermediate member 111 is connected to the perimeter body 22 with flexure assemblies 115A and 115B (herein by example each comprising a connecting web 117) on opposite sides of the intermediate member 111. The flexure assemblies 115A and 115B are substantially stiff for forces along axis 63, but significantly more compliant for forces along axis 61 such that these forces are transferred between the central body 20 and the perimeter body 22 through the flexure components 31 and 33.

In one embodiment each of the pairs of the flexure components 112A, 112B for flexure structures 103 and 104 includes sensor elements to measure component deflection or strain therein. The sensor elements can take any number



of forms known to those skilled in the art, including electrically and optically based sensor elements to name just a few. In the embodiment illustrated, strain gauges are connected in a Wheatstone bridge with strain gauge elements placed on opposite sides of each flexure components **112A**, **112B**. Referring to FIG. **9** and the circuit diagram of FIG. **13**, a Wheatstone bridge **130** includes sensor elements **131** and **132** on opposite sides of flexure component **112A**, while sensor elements **133** and **134** are on opposite sides of flexure component **112B**. FIG. **12** illustrates location of the sensor elements **131** and **133** on the sides of each of the flexure components **112A** and **112B** (i.e. parallel to the sides of the sensor body **102**, rather than between the sides of the sensor body **102**).

Another sensor body is indicated at **202** at FIGS. **14-15**, which can be used in place of the sensor body **12**, described above, in one exemplary embodiment. The sensor body **202** has elements similar in function to that described above with respect to sensor body **12** and sensor body **102** and as such similar elements are identified with the same reference numbers. As illustrated, the sensor body **202** includes flexure components **31** and **33**, intermediate members **41**, connecting members **53** and connecting webs **55-57**. The flexure components **31** and **33** measure forces between the central body **20** and the perimeter body **22** for forces in a direction parallel to axis **61**. Sensor body **202** however includes flexure structures **203** and **204** to transfer forces between the central body **20** and the perimeter body **22** along axis **63**. The flexure structures **203** and **204** are designed to be substantially stiffer than the flexure components **31** and **33** so as to transfer substantially larger forces between the central body **20** and the perimeter body **22**.

Each of the flexure structures **203** and **204** include a flexure component **212** that is rectangular (preferably square) in cross-section along the length thereof, but at least two sides, preferably opposite to each other, are tapered along the length of the flexure component **212** such that one end portion of the flexure component **212** is smaller in cross-section than the other end portion, herein end portion **212A** connected to intermediate member **111** is smaller in cross-section (before connection to intermediate member **111**). In the illustrated embodiment all sides are tapered along the length of the flexure component **212**, i.e. being frusto-pyramidal in a center section. This construction allows the strain field in the center of the flexure component **212** to be approximately 80% (although this value is adjustable based on the shape of the flexure component **212**) of the strain in the connecting fillets at the ends of the flexure component **212**. Each of the sides of the flexure component **212** can include a sensor element such as those described above connected in a conventional Wheatstone bridge (not shown). Strain gauges **231** and **232** are illustrated by way of example.

Yet another sensor body is indicated at **242** at FIGS. **16-21**, which can be used in place of the sensor body **12**, described above, in one exemplary embodiment. The sensor body **242** has elements similar in broad function to that described above with respect to sensor body **12** and as such similar elements are identified with the same reference numbers. As illustrated, the sensor body **242** includes flexure components **251** and **253**, intermediate members **41**, connecting members **53** and connecting webs **55-57**. The flexure components **251** and **253** measure forces between the central body **20** and the perimeter body **22** for forces in a direction parallel to axis **61**. In this embodiment, flexure components **252** and **254**, intermediate members **41**, connecting members **53** and connecting webs **55-57** measure forces between

the central body **20** and the perimeter body **22** for forces in a direction parallel to axis **63** and are also substantially the same as the flexure structures for measuring forces in a direction parallel to axis **61**. However, this is not a requirement as demonstrated by the previous embodiments. Hence, any of the other flexure structures can be used, typically in pairs, but otherwise without limitation, of any of the previous embodiments for either measuring forces in a direction parallel to axis **61** or to axis **63**.

In the embodiment of FIGS. **16-21**, the flexure components **251-254** are very similar to flexure components **31-34**; however, flexure components **251-254** include corresponding apertures **251A**, **252A**, **253A** and **254A**. The strain gauges on the flexure components **251-254** are configured to measure strain in bending (as parallel double cantilever bending beams **255A** and **255B** illustrated in FIG. **20**) rather than to measure strain in shear as flexure components **31-34** operate. Each of the flexure components **251-254** includes sensor elements to measure bending deflection or strain therein. The sensing elements can take any number of forms known to those skilled in the art, including electrically and optically based sensor elements to name just a few. For instance, resistive strain gauges connected in a suitable Wheatstone bridge can be secured to each of the beams **255A** and **255B** of each flexure component **251-254**. In one embodiment, the strain gauges are secured to the inwardly facing surface **254B** of each beam **255A**, **255B** formed by each aperture **251A-254A**, although the strain gauges could also be secured to the outwardly facing surfaces **254C**, which face in opposite directions. Like the flexure components **31-34**, the sensing gauges for sensing deflection of each of the beams **255A** and **255B** are located approximately at the midpoint of each beam **255A**, **255B** of each flexure component **251-254** and where the flexible elements (connecting members **53** and connecting webs **55-57**) of the flexure assemblies are defined by aligned corresponding planes, the planes of which are orthogonal to the direction of compliance and coincide at least approximately with a midpoint along the length of each beam **255A**, **255B** of the corresponding flexure component **251-254**, or stated another way bisect each of the apertures **251A-254A**. The structure of the flexure components **251-254** provides high stiffness with very good resolution and low cross-talk. Although apertures **251-254** are illustrated as round holes, it should be understood that the apertures could be of any suitable shape, such as but not limited to square apertures with rounded corners, or the like, without departing from the scope of the disclosure.

An exemplary embodiment of any of the foregoing transducer bodies with suitable sensing elements to form a transducer assembly can be incorporated in a platform balance **300** an example of which is illustrated in FIGS. **22-23**. In the embodiment illustrated, the platform balance **300** can include a first frame support **302** and a second frame support **304**. A plurality of transducer assemblies **340A-D**, herein four although any number three or more can be used, couple the first frame support **302** to the second frame support **304**. The platform balance **300** can be used to measure forces and moments applied to a test specimen of nominally large weight or mass such as a vehicle, plane, etc. or models thereof. The frame supports **302** and **304** are nominally unstressed reaction frames, wherein each of the transducers comprises a two-axis force transducer as described above. Various levels of flexure isolation can be provided in the platform balance **300** to provide increased sensitivity, while nominally supporting large masses.



The platform balance **300** is particularly well suited for measuring force and/or moments upon a large specimen such as a vehicle in an environment such as a wind tunnel. In this or similar applications, the platform balance **300** can include flexures **315** isolating the frame support **302** and **304** from the test specimen and a ground support mechanism. In the embodiment illustrated, four flexures **315** are provided between each of the transducer assemblies, being coupled to the plates **320**. Similarly, four flexures **324** are coupled to the mounting plates **322**. The flexures **315**, **324** thereby isolate the frame supports **302** and **304**. The flexures **315**, **324** are generally aligned with the sensor bodies of each corresponding transducer assembly.

The platform balance **300** is particularly well suited for use in measuring forces upon a vehicle or other large test specimen in a wind tunnel. In such an application, rolling roadway belts **332** are supported by an intermediate frame **334** coupled to the flexure members **315**. The rolling roadway belts **332** support the vehicle tires. In some embodiments, a single roadway belt is used for all tires of the vehicle. The platform balance **300** and rolling roadway belt assemblies **332** are positioned in a pit and mounted to a turntable mechanism **336** so as to allow the test specimen, for example a vehicle, to be selectively turned with respect to the wind of the wind tunnel.

Each of the frame supports **302** and **304** comprise continuous hollow box components formed in a perimeter so as to provide corresponding stiff assemblies. The frame support **302** holds the sensor bodies in position with respect to each other, while the frame support **304** holds the clevis assemblies in position with respect to each other. Stiffening box frame members **333** can also be provided in the support frame as illustrated.

As appreciated by those skilled in the art, outputs from each of the two-axis sensing circuits from each of the transducer assemblies can be combined so as to sense or provide outputs indicative of forces and moments upon the platform balance in six degrees of freedom. A coordinate system for platform **300** is illustrated at **331**. Output signals from transducer assemblies **340A** and **340C** are used to measure forces along the X-axis, because transducer assemblies **340B** and **340D** are compliant in this direction. Likewise, output signals from transducer assemblies **340B** and **340D** are used to measure forces along the Y-axis, because transducer assemblies **340A** and **340C** are compliant in this direction. Outputs from all of the transducers **340A-340D** are used to measure forces along the Z-axis. The flexure components **251-254** are relatively stiff or rigid for lateral loads, that being in a direction parallel to axis **62**. Overturning moments about the X-axis are measured from the output signals from transducers **340A** and **340C**; while overturning moments about the Y-axis are measured from the output signals from transducers **340B** and **340D**; and while overturning moments about the Z-axis are measured from the output signals from transducers **340A-340D**. Processor **380** receives the output signals from the sensing circuits of the transducers to calculate forces and/or moments as desired, typically with respect to the orthogonal coordinate system **331**.

If desired a counter balance system or assembly can be provided to support the nominal static mass of the test specimen, other components of the operating environment such as roadways, simulators and components of the platform balance itself. The counter balance system can take any one of numerous forms such as airbags, hydraulic or pneumatic devices, or cables with pulleys and counter weights. An important characteristic of the counter balance system is

that it is very compliant so as not to interfere with the sensitivity or measurement of the forces by the transducer assemblies in order to measure all of the forces and moments upon the test specimen. In the embodiment illustrated, the counter balance system is schematically illustrated by actuators **330**.

However, in a further aspect of the present invention, the counter balance system can be removed as explained below, which can be a very large cost savings. Referring back to FIGS. **16** and **18**, the sensor body **242** includes a biasing structure **402** disposed on the sensor body **242** so as to develop a biasing offset force in a selected direction, herein by way of example along the axis **63** in the Z-direction. The biasing structure **402** comprises cantilevered beams **404A** and **404B**. In the embodiment illustrated, remote ends **406A** and **406B** extend in opposite directions where each of the beams **404A** and **404B** are mounted to the sensor body **242** by a base support **408**. It should be noted that use of a single base support **408** is not necessary in that the cantilevered beams **404A** and **404B** can each have a separate base support secured to sensor body **242**; however use of a single base support **408** is of a simpler construction. Likewise, although illustrated with the beams **404A** and **404B** extending in opposite directions alternative embodiments may have the beams extend toward each other. Finally, the biasing structure **402** need not be a cantilevered beam, but can be any structure that is configured to provide a biasing force for the purpose described below.

In the embodiment illustrated the biasing structure **402** can be formed integral with the sensor body **242** from a single unitary body; however, this should not be considered limiting in that individual components can be joined together and/or joined to the sensor body **242** to realize the same structure.

Referring also to FIGS. **24** and **25**, biasing retaining elements **418** connect the biasing structure **402** (located between the clevis halves **16** and **18**) to the clevis halves **16** and **18**. In the embodiment illustrated, the biasing retaining elements **418** operate in tension and herein comprise elongated connectors **420** each joined at a first end **420A** to one of the remote ends **406A** or **406B** with a suitable fastener herein bolts **422**. A second end **420B** of the elongated connectors **420** is joined to both of the clevis halves **16** and **18**, herein by a bridging block **424** separately connected to each of the clevis halves **16** and **18** with a suitable fastener herein bolts **426**.

Biasing retaining elements **418** in one embodiment comprise straps or flexible members. As shown, straps **418**, under tension, are coupled at one end **420A** to a cantilevered beam at its remote end, and are coupled at the other end **420B** to bridging block **424** coupled to clevis halves **16** and **18**. Together, the biasing elements **418**, bridging block **424**, and fasteners such as **422** and **426** comprise a biasing assembly connected between the support (clevis halves **16** and **18**) and the sensor body **12** to provide a bias force between the sensor body **12** and the clevis halves. As shown, a width **423** of the straps **418** is greater than a thickness **425** of the straps **418**. A biasing assembly in one embodiment comprises a pair of straps provided on opposite portions of the transducer body that are symmetric in configuration, to allow for compliance in a direction orthogonal to the offset. For example only and not by way of limitation, the straps **418** may have a square cross-section, that is, an equal width **423** and thickness **425**, or cylindrical, with a constant diameter in every cross-section direction, or other symmetric configurations such as will be evident to those of skill in the art.



A biasing actuator **432** (illustrated schematically with dashed lines) preloads the biasing structure **402** and in particular bends the cantilevered beams **404A** and **404B** by pulling on the bridging block **424** upwardly with the biasing actuator **432** operably connected to standoffs **434**. Any form of actuator can be used such as but not limited to a hydraulic, electric, etc. In one embodiment the actuator **432** comprises a screw or bolt mechanically connecting the standoffs **434** with the bridging block **424**.

A biasing force can be provided as follows. With a loose connection of the bridging block **424** to the clevis halves **16** and **18**, each biasing actuator **432** on each side of the sensor body **242** is operated to obtain the desired preloading on the biasing structure **402** as a whole at which point the bridging blocks **424** are then securely fixed to the clevis halves **16** and **18** to retain the desired bias force. In one embodiment, the bias force from each cantilever **404A** and **404B** is iteratively increased until the desired bias force is obtained. The contribution of the bias force from each cantilever **404A** and **404B** should be the same so as to not induce a moment in the sensor body **242**, but rather provide a purely linear bias force in a direction parallel to axis **63** in the illustrated embodiment.

It should be noted that the biasing structure need not be provided on the sensor body **242**, or only on the sensor body **242**. FIGS. **26-28** illustrate a transducer assembly **500** having many of the same components of the previous transducer assembly, which have been identified with the same reference numbers. In this embodiment though, additional biasing structures **502** have been formed on each of the clevis halves **16** and **18**. The biasing structure **502** is similar to biasing structure **402** discussed above; and thus, much if not all the discussion applicable to biasing structures **402** is applicable to biasing structures **502**. For example, in one embodiment, cantilevered beams **504A** and **504B** and a single base support **508** are integrally formed from a single unitary body; however, this is but one embodiment, where other structures as described above with respect to biasing structure **402** can also be used.

Referring to FIG. **28**, biasing retaining elements **518** connect the biasing structures **502** to the sensor body **242**. In the embodiment illustrated, each of the biasing retaining elements **518** operate in tension and herein comprise elongated connectors **520** with a first end having a bridging block **524** at a first end **520A** connecting the remote ends **506A** or **506B** together with a suitable fastener herein bolts **522**. A second end **520B** of each of the elongated connectors **520** is joined to the sensor body **242**, with a suitable fastener herein bolts **526**. Biasing retaining elements **518** in one embodiment have the properties and characteristics described above with respect to biasing elements **418**.

In this embodiment, sensor body **242** also includes biasing structure **402** having similar components identified with the same reference numbers. A biasing actuator not shown but connectable in a manner similar to that described above and is in effect removably connected to each of the beams **404A**, **404B** so as to pull the beams **404A**, **404B** upwardly in FIG. **28** at which point the retainer **418** is securely fixed to retain the bias force such as by securely fixing the bridging block **424** to the sensor body **242**. In a similar manner, a biasing actuator not shown but connectable in a manner similar to that described above and is in effect removably connected to each of the beams **504A** of each clevis **16**, **18** so as to pull the beams **504A** or **504B** in pairs on each side of the transducer **500** using corresponding bridging blocks **524** and suitable standoffs as needed. When

the desired bias force is obtained in each pair of beams **504A** and **504B**, the associated end **520B** of the bias retainer **518** can be securely fixed to the sensor body **242**. As in the previous discussion of bias structure **402**, any form of actuator can be used such as but not limited to screws or bolts, hydraulic, electric, etc.

An overtravel stop can be provided to limit the bias force created by the pairs of beams **504A** and **504B** on the clevis halves **16** and **18**. Referring to FIGS. **29** and **30**, a bolt **550** is secured to support **408** and extends through an aperture **552** provided in element **17** connecting the clevis halves **16**, **18** together. The head of the bolt **550** is of size to be larger than the aperture **552**. The bolt **552** is secured to the support **408** with the head of the bolt spaced apart from a surface of the connecting element a selected distance corresponding to a limit of bias force to be generated by beams **504A** and **504B**. Since loading of beams **504A** and **504B** causes the sensor body **242** to move upwardly in FIG. **29**, contact of the head of the bolt **552** limits the bias force that can be generated.

Another aspect of the present invention is a lock up assembly **600** that selectively secures the position of the sensor body **12** relative to the clevis halves **16** and **18**. Referring to FIGS. **31** and **32**, the lock up assembly **600** includes friction plates **602** attached to each of the clevis halves. Each friction plate **602** is attached to its corresponding clevis half with a fastener **604** such as a plurality of fasteners in the center of the plate. However, it should be noted that only the center of the plate is in permanent contact with the corresponding clevis halves in that the extending ends **606** of the friction plates **602** are spaced apart from the outer surface of the corresponding clevis half. A spacer **608** is securely fixed to the sensor body and is disposed between ends **606** of the friction plates **602** on each side of the transducer. The length of the spacer **608** is slightly shorter than the distance between the inner surfaces of the friction plates such that a gap **610** is present between one or both of the end surfaces of the spacer **608** and corresponding inwardly facing surfaces **612** of the friction plates **602**. An actuator **614** is operably coupled to the friction plates **602**. The actuator **614** includes a pull rod **616** that extends through a bore **618** in the spacer. The bore **618** is of size to maintain a gap between the pull rod **616** and the spacer **618** for movements of the sensor body **12** or the clevis halves **16** and **18** relative to the sensor body **12**. When it is desired to inhibit movement of the sensor body **12** relative to the clevis halves **16** and **18**, the actuator **614** is operated so as to retract the pull rod **616** which pulls the ends **606** of the friction plates **602** together thereby eliminating the gap(s) **610** between the end surface(s) of the spacer **608** and the inwardly facing surface(s) **612** of the friction plates **602** as well as eliminating the gap(s) **620** between the inwardly facing surface(s) **612** of the friction plates **602** and the outwardly facing surface **622** of each corresponding clevis half. As such, when the actuator **614** is operated, a solid connection is formed between the spacer **608** and the friction plates **602** wherein the friction plates **602** frictionally engage the outer surfaces **622** of each corresponding clevis half.

The actuator **614** can be of any suitable form such as but not limited to an electric, hydraulic, or pneumatic actuator.

In the embodiment illustrated, each of the friction plates **602** includes areas of reduced thickness that form flexible hinges **624**. The flexible hinges **624** ensure that the ends **606** of the friction plates **602** will maximize contact of the end surfaces of the friction plates **602** with the clevis halves **16** and **18** rather than being slightly at an angle if the flexible hinges **624** were not present. In other words, the portion of



the friction plates **602** that secure the friction plates **602** to the clevis halves by the fasteners indicated at **604** is maintained in a planar fashion to the corresponding clevis halves. Likewise, when the actuator **614** is operated, each of the end portions **606** of the friction plates **602** will contact the corresponding clevis half in a planar fashion. Any slight difference in width between the center sections of the friction plates **602** and the end portions of the friction plates **602** is accommodated by the middle sections between each of the flexible hinges **624**.

The embodiments pre-loading the transducer body with respect to the clevis plates, as shown and described above, allow for accurate full scale measurement even if the tare weight placed on the platform **300** is many times a full scale measure load weight. For example, a 20,000 pound upper frame is supportable with four transducer bodies while still allowing accurate measurement of loads in a full scale measure load of  $\pm 2,000$  pounds vertical, without frequency degradation of a dead-weight type tare system. Such embodiments are amenable to use with other load cells where tare mitigation is employed, without departing from the scope of the disclosure.

In such a pre-loading, thermal expansion differences can lead to thermal structural temperature equilibration between components of the transducer body and any sensing elements therein. Thermal expansion differences between, for example, parallel springs (e.g., the cantilevered beams) in series with straps and those in parallel with gauged beam assemblies, and the resulting disparate temperatures between elements, may result in thermal drift for a duration of a test.

FIG. **33** shows a fluid enclosure **700** for a transducer assembly such as the various transducer assembly embodiments described herein. In one embodiment, fluid enclosure **700** is an oil enclosure or oil bath, such as a fluid recirculating bath assembly. Elements of the transducer, especially straps, cantilevered beams, gauged elements, sensor body, clevis plates, and bottom plates, are immersed in the fluid of the fluid enclosure **700**, and are held in one embodiment to a same temperature with a tolerance of about  $0.1^\circ$  F. for a testing cycle. In one embodiment, fluid enclosure **700** contains an oil **702** heated to a desired temperature at which the elements of the transducer are to be held. Oil **702** has high thermal mass and very good heat conduction and convection to and with the elements of the transducer assembly. This allows maintenance of thermal uniformity within a desired tolerance even when the transducer assembly is in an operating wind tunnel.

Oil enclosure **700** further comprises cross flow inlets **704** and outlets **706**, and a fluid circulating bath tank **708** mounted to a plate **710**. A gasket **712** seals tank **708** to plate **710** in one embodiment. Further gaskets **714** may be used to seal plate **710** to a bottom plate such as connecting member **17** of a transducer body (FIG. **1**), for example by sealing each bolt between bottom flexures **716** and connecting member **17**, or by sealing with a larger gasket around a circumference of the bottom flexures **716**. Top flexures **718** may be coupled, for example with bolts, to the sensor body of the transducer assembly. Associated plumbing (not shown) provides oil **702** at the desired temperature for the components to the enclosure **700** via inlets **704**, recirculated to the plumbing and heater (not shown) via outlets **706**. A top cover **720**, shown in FIG. **34**, may be used to provide protection against contaminants such as dirt or dust into the tank **708**. In one embodiment, oil is provided to fill tank **708** to fill line **722**, so that sensing elements that may be in the transducer body are completely submerged in the oil.

Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above as has been held by the courts. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

What is claimed is:

1. A transducer body, comprising: a support comprising a pair of clevis halves; and sensor body coupled to each of the clevis halves, wherein the sensor body is disposed between the clevis halves and configured to deflect with forces along two orthogonal axes, wherein the sensor body includes a peripheral member disposed about a spaced-apart central hub, the central hub being joined to each of the clevis halves with the peripheral member spaced apart from each clevis half, wherein at least three flexure components couple the peripheral member to the central hub, and wherein the flexure components are spaced-apart from each other at angular intervals about the central hub; the sensor body further including a flexure assembly for each of said at least three flexure components joining its flexure component to at least one of the central hub and the peripheral member, each flexure assembly being compliant for forces in a radial direction from the central hub through the flexure component and to the peripheral member, wherein at least two flexure assemblies are configured such that forces transferred between the central hub and the peripheral member concentrate strain at a midpoint along a longitudinal length of each corresponding flexure component configured for strain measurement, and wherein the at least two flexure assemblies and the corresponding flexure component midpoint are collinear.

2. The transducer body of claim 1 wherein each flexure assembly is configured such that forces transferred between central hub and the peripheral member cause a first force at the connection of the flexure component to the central hub to be equal and opposite to a second force at the connection of the flexure component to the peripheral member, wherein the first and second force are tangential to the radial direction of each corresponding flexure component.

3. The transducer body of claim 1 wherein at least two flexure components are configured to concentrate strain in shear.

4. The transducer body of claim 1 wherein at least two flexure components are configured to concentrate strain in bending.

5. The transducer body of claim 1 wherein at least two flexure components are configured with a pair of beams.

6. The transducer body of claim 5 wherein the pair of beams of each flexure component of said at least two flexure components is formed by an aperture.

7. The transducer body of claim 1, and further comprising: a biasing assembly connected between the support and the sensor body and configured to provide a bias force between the sensor body and the support.

8. The transducer body of claim 7 wherein the biasing assembly comprises a bias connector configured to operate in tension to provide the bias force.

9. The transducer body of claim 8 wherein the biasing assembly comprises a removable biasing actuator configured to be connected between the sensor body and the support.

10. The transducer body of claim 8 wherein the bias connector comprises an elongated strap having a width of the strap greater than a thickness of the strap.



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11. The transducer body of claim 10 wherein the biasing assembly comprises a pair of straps provided on opposite portions of the transducer body that are symmetrical.

12. The transducer body of claim 11 wherein the biasing connector comprises a flexible member fixedly connected to one of the sensor body or the support.

13. The transducer body of claim 12 wherein each flexible member comprises a cantilevered beam with one of the biasing connectors connected to one of the flexible members.

14. The transducer body of claim 12 wherein the flexible member is integrally formed from a single unitary body of one of the sensor body or the support.

15. The transducer body of claim 14 wherein the flexible member is provided on the sensor body.

16. The transducer body of claim 14 wherein the flexible member is provided on the support.

17. The transducer body of claim 10 wherein the biasing assembly comprises a pair of biasing connectors wherein a biasing connector is provided each of opposite portions of the transducer body that are symmetrical.

18. The transducer body of claim 17 wherein a flexible member is provided on each clevis half and a bridging block connects the flexible members together, the bridging block being spaced apart from the sensor body.

19. The transducer body of claim 17 wherein the biasing assembly comprises flexible members, a flexible member being fixedly connected to one of the sensor body or the support.

20. The transducer body of claim 19 wherein the flexible members are integrally formed from a single unitary body of one of the sensor body or the support.

21. The transducer body of claim 1, and further comprising:

a lockup assembly configured to selectively inhibit movement of the sensor body relative to the clevis halves.

22. The transducer body of claim 21 wherein the lockup assembly is configured to inhibit movement of the peripheral member relative to the clevis halves.

23. The transducer body of claim 22 wherein the lockup assembly inhibits movement of the peripheral member by frictional contact.

24. The transducer body of claim 23 wherein the lockup assembly is configured to selectively move portions having engaging surfaces for frictional contact to contact opposed surfaces of the peripheral member, the engaging surfaces and the opposed surfaces being spaced apart from each other to allow forces to be transferred by the flexure components when the lockup assembly is not engaged.

25. The transducer body of claim 24 wherein the lockup assembly comprises a first plate member joined to a first clevis half and a second plate member joined to a second clevis half, wherein the engaging surfaces are disposed on the plate members.

26. The transducer body of claim 25 wherein a portion of each plate member is spaced apart from the associated clevis half.

27. The transducer body of claim 26 wherein when the engaging surfaces engage the opposed surfaces, the portion of each plate member frictionally engages the associated clevis half.

28. The transducer body of claim 27 and further comprising an actuator configured to selectively bring the engaging

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surfaces in contact with the opposed surfaces and also bring the portions of each plate member into contact with each associated clevis half.

29. The transducer body of claim 28 wherein major surfaces of the portions of the plate members engage major surfaces of the associated clevis halves.

30. The transducer body of claim 29 wherein the engaging surfaces are on the plate members, and wherein each plate member comprises a hinges and a link portion between the hinges, the link portion connecting portions of the plate members having the engaging surfaces with portions of the plate members having the major surfaces.

31. The transducer body of claim 30 wherein the actuator is operably mounted to the portions of the plate members having the engaging surfaces, and wherein the actuator includes a pull rod to selectively pull the pull rod so as to bring the engaging surfaces in contact with the opposed surfaces.

32. The transducer body of claim 31 wherein the pull rod extends through a bore opening to one of the opposed surfaces, the pull rod being spaced apart from inner surfaces of the bore at least when the actuator is not pulling on the pull rod to bring the engaging surfaces in contact with the opposed surfaces.

33. The sensor body of claim 1 and further comprising a strain sensor operably coupled to the midpoint of each flexure component.

34. A transducer body, comprising: a support comprising a pair of clevis halves; and a sensor body coupled to each of the clevis halves, wherein the sensor body is disposed between the clevis halves and configured to deflect with forces along two orthogonal axes, wherein the sensor body includes a peripheral member disposed about a spaced-apart central hub, the central hub being joined to each of the clevis halves with the peripheral member spaced apart from each clevis half, wherein at least three flexure components couple the peripheral member to the central hub, and wherein the flexure components are spaced-apart from each other at angular intervals about the central hub; the sensor body further including a flexure assembly for each of said at least three flexure components joining its flexure component to at least one of the central hub and the peripheral member, the flexure assembly being compliant for forces in a radial direction from the central hub through the flexure component and to the peripheral member, wherein each of at least two flexure assemblies comprises a first connecting web orthogonal to its flexure component, and the first connecting web is disposed to be approximately in line with a midpoint along a longitudinal length of its corresponding flexure component, wherein forces transferred between the central hub and the peripheral member concentrate strain at the midpoint of each corresponding flexure component configured for strain measurement, and wherein the at least two flexure assemblies and the corresponding flexure component midpoint are collinear.

35. The sensor body of claim 34, wherein each of said at least two flexure assemblies comprises a second connecting web on a side of the corresponding flexure component opposite the corresponding first connecting web.

36. The sensor body of claim 34 and further comprising a strain sensor operably coupled to the midpoint of each flexure component.

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